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JOURNAL

AIR POLLUTION CONTROL ASSOCIATION

SCW

Founded 1907

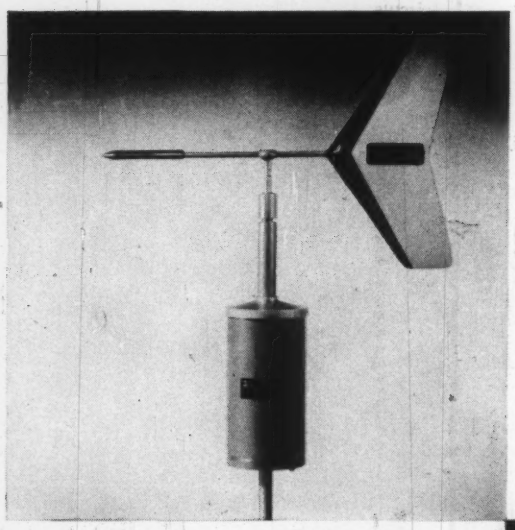
SCIENCE & TECHNOLOGY

Charles N. Howison, "Mr. Cleaner Air Week"

FOR SYSTEM APPLICATION

Climate Survey

Wind Transmitters



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← WIND COMPONENT TRANSMITTERS with low threshold, providing sine and cosine vector resolution for wind-component determination. Also standard linear wind-direction transmitters in the same basic design.

→ WIND SPEED TRANSMITTERS based on dragfree light-beam chopper design, available in standard types providing one, two, four, and 100 pulses per revolution. Complete series housed in identical environment-proved package with triple-labyrinth dust-seals, selected and specially-processed low friction bearings. Extremely rapid transient response —guaranteed threshold three-quarters mile per hour.

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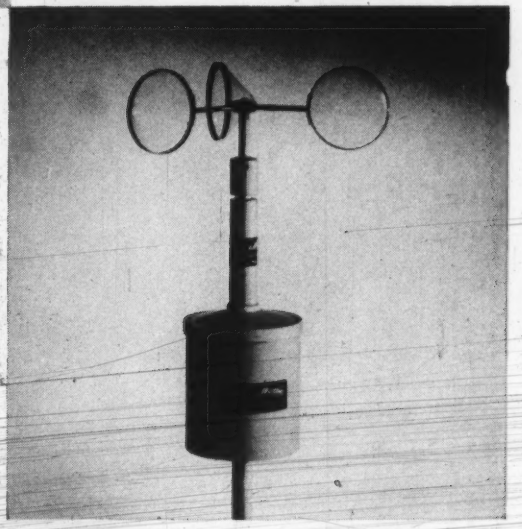

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instruments for scientific meteorology

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Pangborn Dust Collectors trap industrial dusts at the source. By doing so, they reduce the hazards of industrial dust. Employee health is safeguarded . . . morale is higher, efficiency is increased . . . and community relations are improved.

Pangborn Dust Control pares operating costs, too, by:

1. Cutting machinery maintenance costs, saving parts and labor costs, down-time.
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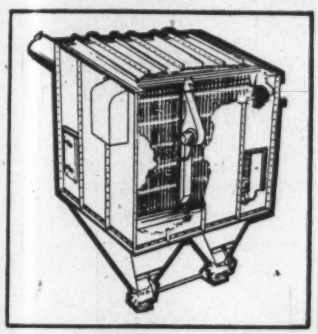
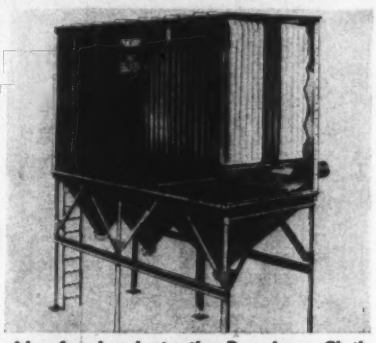
4. Cutting heating costs. Many plants re-circulate the already-heated cleaned air.

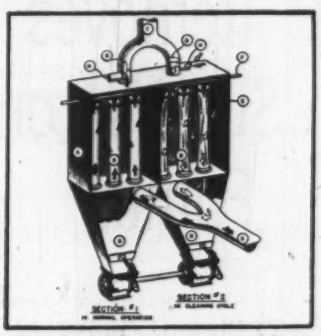
Which Pangborn Dust Collector do you need?



For automatic, continuous operation, the Pangborn Self-Cleaning Collector . . . combining the proved efficiency of the cloth screen collector with continuous operation, uniform air flow.



Also for dry dusts, the Pangborn Cloth Bag Collector . . . an efficient, economical method of dust control. Its simplified design and construction involves a minimum of parts. Easily inspected and maintained.



For elevated temperature fume and dust problems, the Pangborn Cloth Tube Collector featuring Pressure-Jet fabric cleaning developed specially for glass fibre fabrics.

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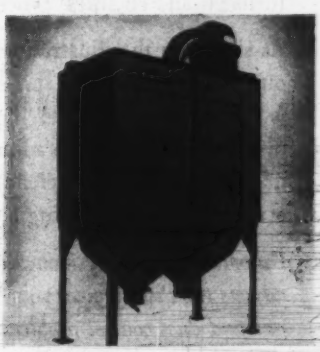
The Pangborn Ventrijet Wet Collector . . . for hot, moist and other dusts that a dry collector cannot handle. Compact, self-contained unit with low headroom. Inexpensive to maintain and operate.



For small volume applications, the Pangborn Unit Type Collector . . . a self-contained unit, shipped assembled ready for installation. Seven sizes, ranging from 200 to 1,000 sq. ft. of cloth area.

NOTE: Bulletins are available on all Pangborn Dust Collectors. For your copy or more details, write PANGBORN CORPORATION, 5100 Pangborn Blvd., Hagerstown, Md. *Manufacturers of Dust Control, Blast Cleaning, Vibratory Equipment—Rotoblast® Steel Shot and Grit®.*

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*Completely adjustable**

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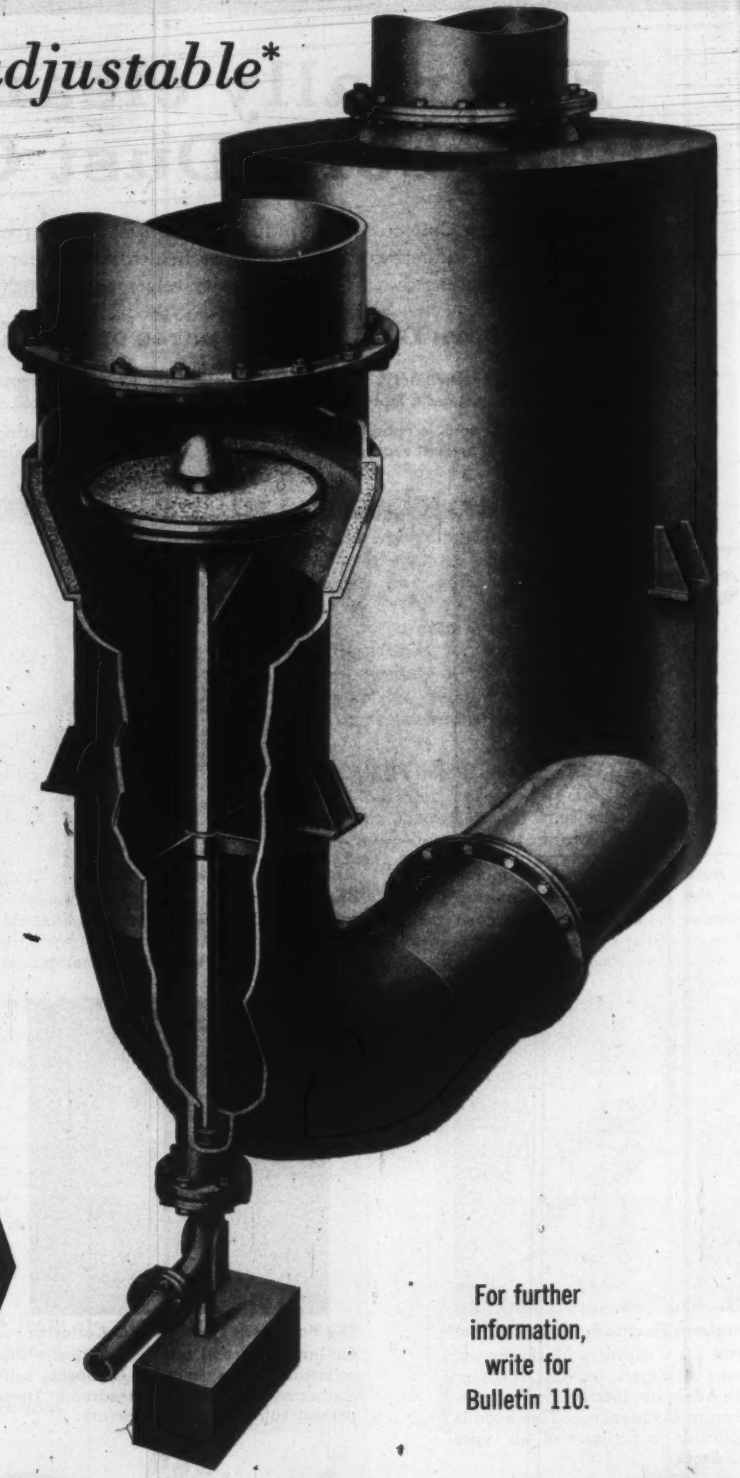
Removes Sub-Micron Fumes



The Research-Cottrell high efficiency scrubber uses the unique flooded disc principle for removing sub-micron fumes in steel-making furnaces and chemical processing.

As shown in the illustration, the outstanding feature of this scrubber is the simple, adjustable "flooded disc." The flooded disc adjusts for maximum cleaning efficiency over a wide range of operating conditions.

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Research-Cottrell, with over 48 years of industrial gas cleaning experience, will be glad to consult with you on any specific problem.

For further information, write for Bulletin 110.

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JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

A Bi-Monthly Journal
Devoted to
Air Purification

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Assistant Editor: Pat Martin

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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In Charlotte, North Carolina

A. I. S. I. SAMPLER readings reveal year-to-year improvements in AIR POLLUTION CONTROL

By making a graph of A.I.S.I. Sampler readings in Coh Units, Charles S. Frost, Director of the Charlotte, N. C. Department of Air Pollution Control, maintains an hour-by-hour, day-to-day, and year-to-year record of air pollution conditions in Charlotte.

Results of any air pollution regulations put into effect can be determined almost immediately by reading the A.I.S.I. Sampler recordings.

Charlotte, which is constantly improving conditions in cleaner air, is one of many municipalities throughout the country who are maintaining air pollution records based on the readings of the A.I.S.I. Sampler.

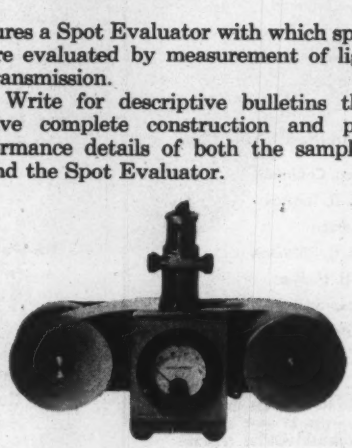
The low cost of the A.I.S.I. Sampler makes it feasible to locate a large number of them for complete coverage of a geographical area; and its quiet operation overcomes any objections to its location in or near individual residences.

Research Appliance Company manufactures another sampler, the A.I.S.I. Hydrogen Sulphide Sampler, which measures the amount of hydrogen sulphide in the air. It can indicate H_2S concentration as low as one part per billion parts of air.

It operates on the same principle as the Air Sampler, but is fitted with an air filter to remove suspended solids; and the tape assembly is enclosed to prevent blackening of the tape, outside the sample spot.

TO ANALYZE THE SPOTS, Research Appliance Company manufactures a Spot Evaluator with which spots are evaluated by measurement of light transmission.

Write for descriptive bulletins that give complete construction and performance details of both the samplers and the Spot Evaluator.



RESEARCH APPLIANCE COMPANY

Box 307 Allison Park, Pa.

LETTERS to the EDITOR

Dear Mr. Belyea:

Congratulations on the very fine President's message which has appeared in the August issue of the Journal. I hope that the members will take heed of your message and do their part in charting "THE FUTURE OF APCA".

This is certainly a fine beginning to your year in office and I hope that in future issues of APCA additional messages in charting "THE FUTURE OF APCA."

CHAS. W. GRUBER
Air Pollution Control and Heating Engineer

Western Union Telegram

Charles N. Howison, Chairman

The twelfth annual observance of cleaner air week emphasizes the continuing need for greater public effort to solve the problems caused by the hazard of air pollution. This year there are indications of a renewed awareness of the seriousness of air pollution as a threat to human life and property.

Activities connected with cleaner air week call attention to the importance of the research and control programs carried out by private and governmental groups. By these means the public is reminded that air pollution is an individual and community problem—its solution is everyone's gain.

DWIGHT D. EISENHOWER
White House,
Washington, D.C.

NOTICE

NEW DATES FOR 54th ANNUAL MEETING OF APCA

JUNE 11–15, 1961

These new dates have been obtained by popular demand of APCA membership through the co-operation of the Hotel Commodore management.

SECRETARY'S PAGE

APCA'S PROGRESS

The practice of using the pictures of APCA personalities on the cover of the *Journal* is a new one. The cover this month is dedicated to Charles N. Howison, Executive Secretary, of the Air Pollution Control League of Greater Cincinnati who is affectionately known as "Mr. Cleaner Air Week." APCA has many devoted workers, but Charlie Howison exemplifies a person who has devoted practically all his life to publicizing clean air. It is only proper that the letters to the editor should include communications which Charlie has received from the Secretary of Commerce and the President of the United States upon the occasion of the Twelfth Annual celebration of Cleaner Air Week from October 23 to 29. The planning of the Cleaner Air Week Committee should make this one the most successful of all.

Your attention is called to the announcement of the change of dates for the 54th Annual Meeting in New York. The new dates are June 11 through 15, 1961 at the Hotel Commodore.

Some of the important actions of the Board of Directors during the May 22 and 23 meetings of the Board were:

1. The advertising rate schedule for the Journal was discussed fully and a recommendation made for increasing the rate schedule. A $55^1/_2\%$ rate increase was approved shortly after the Board meeting.
2. The Board reaffirmed present policies of the Editorial Review Committee in handling the review and publication of Annual Meeting papers in the Journal.
3. The price of preprints and reprints after annual meetings to members was set at $1 per copy for members, $1.50 for non-members and $2 for non-members overseas.
4. Price structure of other publications to be set by headquarters after cost studies are made in conjunction with APCA's publisher.
5. A By-Law amendment spelling out powers of the Executive Committee was approved subject to review and approval of the Legal Committee.
6. A By-Law amendment clarifying succession of presidency as recommended by the Legal Committee was approved.
7. The appointment of an ad hoc committee to study relationships of local sections to the national organization was approved and the President was empowered to appoint this ad hoc committee. Louis E. Bunts has been appointed chairman.
8. Extension of the APCA Abstracts contract with the U. S. Public Health Service was authorized for the year 1960–61.
9. The Ontario Section of APCA was recognized.

The Executive Committee of APCA composed of President Harry Belyea, First Vice-President W. L. Faith, and Vice President L. E. Bunts, C. C. Tate and C. G. MacKenzie met at headquarters in Pittsburgh on August 23 and 24.

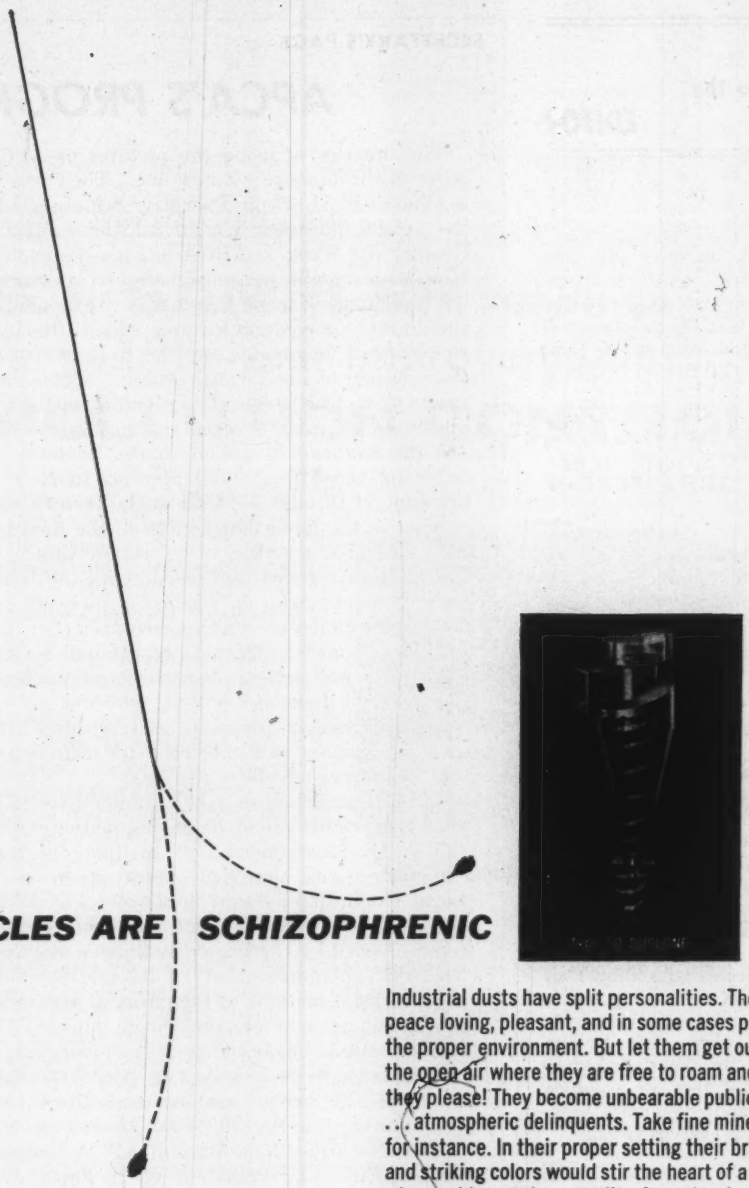
The Editorial Review Committee has been extremely active since the Annual Meeting. *Results:* all authors were notified of acceptance or rejection of papers delivered in Cincinnati with tentative publication dates within the 90-day period specified after Annual Meeting.

The Technical Council will meet in Pittsburgh on November 15. Council has been extremely active as indicated by the number of reports published in recent Journal. All members with items of interest for the Journal are invited and encouraged to submit these stories to headquarters for inclusion in the Journal. Closing dates for copy are the first of the month prior to publication date.

The Board of Directors is slated to meet in Pittsburgh on October 25.

It is essential that the questionaires mailed out with ballot on increased dues be returned to APCA headquarters.

Arnold Arch



DUST PARTICLES ARE SCHIZOPHRENIC

Industrial dusts have split personalities. They can be peace loving, pleasant, and in some cases precious . . . in the proper environment. But let them get out into the open air where they are free to roam and settle where they please! They become unbearable public enemies . . . atmospheric delinquents. Take fine mineral particles, for instance. In their proper setting their brilliance and striking colors would stir the heart of a poet. But who would want them settling from the sky on a white suit or staining a newly painted house? Esthetic beauty in one place can be unwanted ugliness in another.

Let Ducon dust specialists psychoanalyze your industrial dust and prescribe the right treatment to keep it under control. We have a full line of wet and dry dust control devices to solve your problem.

Write for Bulletin C 1058

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THE Ducon COMPANY INC.

147 EAST SECOND STREET • MINEOLA, L. I., NEW YORK

CYCLONES • CENTRIFUGAL WASH COLLECTORS • TUBULAR CLOTH FILTERS • DUST VALVES

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TOTAL *Air Pollution* EMISSIONS *in* LOS ANGELES COUNTY*

ROBERT L. CHASS, Director of Engineering, **PHILIP S. TOW,** Senior Research Assistant,
ROBERT G. LUNCHE, Assistant Director of Engineering,
NORMAN R. SHAFFER, Intermediate Air Pollution Engineer,
L. A. County Air Pollution Control District, Los Angeles, Calif.

From the time that a person begins his technical training he is taught that an engineering or scientific problem cannot be solved intelligently until the problem is defined. Unfortunately, this philosophy is not always followed in air pollution control work. Too many times, consulting engineers, plant superintendents, plant managers, equipment suppliers, and control officers apply a control device which has proved successful on one installation to another type basic equipment that they believe may be similar, without taking the necessary time and effort to determine the degree of similarity. In such cases, a little information proves to be most harmful.

Because of necessity, the Los Angeles County Air Pollution Control District has had to promulgate the most stringent regulations possible for sources of air contaminants as soon as sound technical and economically feasible controls have become known. With few exceptions, industrial sources have been controlled during the past ten years. Rules and regulations have been promulgated against particulate matter, dusts and fumes, sulfur dioxide, combustion contaminants, storage of petroleum products, open fires, single chamber incinerators, oil-effluent water separators, gasoline loading, burning of fuel oil, and orchard heaters. At the present time there is in the making a rule which would establish maximum limits for the olefinic content of gasoline. The control program will not be completed until control is achieved for the three major remaining sources of air pollution—the automobile exhaust, the evaporation of organic liquids, and the combustion of fuels.

Before standards were established in the rules adopted by the APCD, considerable information had to be gathered, correlated, and evaluated to insure that the rules would result in reducing the emissions of air contaminants to the degree necessary. A rule or regulation cannot be arbitrary, unreasonable, capricious, or confiscatory. Without proper technical substantiation, legislation will not withstand the test of time. The matter of economics, of course, must also be considered. This is an area in which there is wide latitude for disagreement, depending on whether the problem is approached on an individual source basis or on a community-wide basis. It is generally conceded that such matters must be judged on what is best for the majority.

To gain the information upon which a rule must be based (which will also include the basis for the type of control devices that will eventually have to be installed), it is necessary to determine the magnitude of the problem, the extent to which control is essential and the major sources of the contaminants so that a "breaking-off" point can be fixed. It is obvious that a rule cannot require 100 percent control. Where the "breaking-off" point is established depends upon the information gathered during the investigation and study.

Since there are no recognized formulae for appraising improvements in air pollution levels, several approaches must be used to evaluate the reduction of the various contaminants affected by a control program. Studies to determine the dispersion characteristics of the atmosphere, accumulations of data from air monitoring programs, and studies of the tonnages of materials emitted to the atmosphere must form the bases for judging progress.

For the past eight years the District has maintained a Total Air Pollution Survey which includes statistics by category of source on the emissions of all types of air contaminants being emitted into the atmosphere daily. This continuous survey is made for several reasons: first, it is invaluable in serving as a method for evaluating the progress of the total control effort; second, it is useful as a comparison with the atmospheric concentrations obtained through the air monitoring program; third, it indicates clearly those sources requiring maximum effort.

These total air pollution estimates have been obtained through a combination of the several methods. Through the years, correlations between production tonnages and emissions to the atmosphere have been established for each type operation. Hence, the amount of information required to maintain these records on a current basis is minimized considerably. The

Table I—Los Angeles County Air Pollution Control District Classification of Air Contaminants

Major Classes of Air Contaminants	Subclasses of Air Contaminants	Typical Members of Subclasses
Organic gases	Hydrocarbons	Hexane, benzene, ethylene, methane, butane, butadiene
	Aldehydes and ketones	Formaldehyde, acetone
	Other organics	Chlorinated hydrocarbons, alcohols
Inorganic gases	Oxides of nitrogen	Nitrogen dioxide, nitric oxide
	Oxides of sulfur	Sulfur dioxide, sulfur trioxide
	Carbon monoxide	Carbon monoxide
	Other inorganics	Hydrogen sulfide, ammonia, chlorine
Aerosols	Solid particulate matter	Dusts, smoke, fumes
	Liquid particulate matter	Oil mists, entrained liquid droplets

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 22–26, 1959, Los Angeles, Calif.

Table II—Current Statistics for Los Angeles County

Item	Quantity
Population	6,020,000
Total employees in manufacturing	740,000
Gasoline powered vehicle registration	3,105,000
Diesel powered vehicle registration	9,000
Gasoline consumed by vehicles, gal/day	6,075,000
Diesel fuel consumed by vehicles, gal/day	100,000
Fuel oil consumed by industrial combustion sources, gal/day[a]	2,740,000
Natural gas consumed by industrial combustion sources, gal/day[a, b]	3,030,000
Refinery gas consumed by industrial combustion sources, gal/day[a, b]	1,710,000
Fuel oil consumed by domestic and commercial combustion sources, gal/day[a]	194,000
Natural gas consumed by domestic and commercial combustion sources, gal/day[a, b]	3,990,000
Solvents used for all purposes, lb/day	1,000,000
Refinery crude oil throughput, bbl/day	650,000

[a] During months when Rule 62 is not in effect.
[b] Equivalent gal/day on a Btu basis.

results of this continuous project serve also as a basis for determining the need to revise existing rules.

Air Contaminant Classifications

In any community, and Los Angeles County is no exception, there are many sources of man-made and natural air pollution. From them a broad variety of air contaminants are discharged into the atmosphere. For convenience, the numerous air contaminants may be classified by physical state as gaseous or non-gaseous. Those in the gaseous state may be further classified as "organic gases" or "inorganic gases." Those in the non-gaseous state are known as "aerosols," and include all solid or liquid particulate matter such as smoke, dusts, fumes, or mists. Table I presents a detailed tabulation of the air contaminant classifications used by the Los Angeles County Air Pollution Control District.

Some contaminants, sulfur dioxide and fluorides for example, are demonstrably toxic to plants or animals. Others are known to cause eye irritation, nasal irritation, throat irritation, visibility reduction, soiling or corrosive effects. Some contaminants are suspected of being involved in more serious public health problems. These facts are sufficiently important in themselves to provoke studies of the respective contaminants, their sources, quantities emitted, and effects upon the quality of the air we breathe. This paper deals primarily with those phases and results of studies conducted by the Los Angeles County Air Pollution Control District relative to sources of air pollution and the nature and quantities of air contaminant emissions. Secondarily, other associated aspects, effects of controls and presenting and applying the results, are briefly discussed.

Survey Techniques

The determination and evaluation of types and quantities of air contaminants emitted from air pollution sources are accomplished through a combination of many procedures. Review of literature and records, physical inspections of equipment and operations, collection and analyses of effluent samples, measurements of flow rates, material balances, data reduction calculations, and surveys of uses and practices are all essential to the preparation of estimates of air contaminant emissions. In certain instances, reliable emission factors existing from previous studies can be used in conjunction with appropriate statistics to yield estimates of total air pollution emissions.

A considerable amount of valuable information for total air pollution studies is derived from statistics published by Chambers of Commerce, governmental agencies, research organizations, scientific publications, etc. These statistics include information on new and existing industries, population growth and distribution, vehicle registration, and fuel usage. Unfortunately, these statistics do not always provide the information desired in an applicable form and must be supplemented with data from utilities, industrial associations, and even individual companies. Table II illustrates typical statistics which were used for estimating total air pollution emissions in Los Angeles County. These should allow comparisons between Los Angeles County and other communities of some factors important to estimates of air pollution emissions.

When a total air pollution study of a specific contaminant, industry or operation has been completed, the emission values cannot be considered permanent. Revisions of total air pollution estimates are required on a continuous basis because of industrial expansion, population changes, more test data, adoption of air pollution controls and introduction of new processes, techniques, and materials.

Usually, several steps are involved in the estimation of air pollution emissions from single operations or processes and their extrapolation to total air pollution emissions for all such operations in a given community. One must know materials used, processes and equipment involved, location of points of emission, operation schedules followed, control measures employed, composition, and quantity of effluents. Detailed questionnaires can be prepared requesting this specific information or the sources under consideration can, of course, be inspected by field personnel, either to constitute the survey itself or to implement the questionnaire. In addition to the questionnaire and field inspections, it is most often necessary to obtain actual data of stack emissions by sampling the specific sources. Many control agencies have the authority to require information from any person operating sources capable of emitting air contaminants to the atmosphere.* On many occasions large discrepancies have been found among the information and data furnished by the operator, those obtained by the field inspector, and those obtained by test. Perseverance and further investigation can usually clarify this type dilemma.

The question is often asked, "How can questionnaires be sent to operators of sources under consideration if the sources and operators are not known?" One must exercise ingenuity and initiative. In many cases, lists must be used which are not necessarily too accurate for the purpose but have the possibility of containing some of the sources of interest. Lists compiled by the chambers of commerce, telephone companies, fire departments, business license agencies, building departments, tax offices, planning commissions, and industrial waste departments are most useful as a starting point in any survey. A check of raw material suppliers can prove most helpful in ascertaining the degree of completeness of the final list.

As can be expected, it is sometimes necessary to send follow-up letters, but in a typical survey, response to our first letter is about 50 percent, after the second letter the overall response is 80 percent. In some instances a third letter, phone call, or personal visit is scheduled to obtain 100 percent response. Usually, it is found scheduled to obtain 100 percent

* Section 24269 of the Health and Safety Code of the State of California states, "The air pollution control officer at any time may require from an applicant for, or holder of any permit provided for by the regulations of the air pollution control board, such information, analyses, plans, or specifications as will disclose the nature, extent, quantity, or degree of air contaminants which are or may be discharged by such source."

SURVEY OF ORGANIC SOLVENTS, THINNERS AND DILUENTS MANUFACTURED OR SOLD IN LOS ANGELES COUNTY

Company Name _____ Address _____ Phone No. _____

Production and Sales Data / Products:*	Mineral Spirits and Terpenes	Aromatic Hydrocarbons	Alcohols and Glycol Ethers	Ketones	Esters	Chlorinated Hydrocarbons	Others
Monthly production in L. A. County (1957 average; gal/mo)							
Per cent of production which is reclaimed solvent							
Monthly sales to buyers in L. A. County (1957 avg. gals/mo)							
Per cent of sales to each of following buyers in L.A.Co.(1957)							
a. Distributors, repackagers, etc. for resale							
b. Paint, varnish, lacquer, mfrs.							
c. Plastic, resin, putty mfrs.							
d. Rubber products mfrs.							
e. Furniture mfrs.							
f. Automobile mfrs.							
g. Dry cleaners							
h. Degreasing operators							
i. Metal container mfrs.							
j. Pharmaceutical mfrs.							
k. Aircraft mfrs.							
l.							
m.							
n.							

*Please use list on reverse side as a guide to classifying solvents.

Remarks: (Include name of local sales outlet, if any) _____

Signature of Responsible Official: _____

Title: _____

Fig. 1. Example of a questionnaire form used in survey of organic solvents sold in Los Angeles County.

response. Usually, it is found in these latter cases that answers to the questionnaire have not been forthcoming because the plant is no longer in operation rather than from willful refusal.

When all the survey information has been received, reviewed, and evaluated, it may be used directly in calculation of air pollution emission estimates for each source or may be tabulated and used in calculations for over-all emissions from various categories. Where possible, the use of emission factors eliminates time-consuming, expensive testing programs and extensive surveys of individual sources and accelerates the determination of total air pollution emission values.

"Short-cuts" to obtain estimates of air pollution emissions are sometimes feasible. For example, in an organic solvent survey, it is much easier and quicker to contact a relatively few suppliers of solvents than all the many users. (Fig. 1.) This is also true in the case of emissions from natural gas burning, in that amounts of natural gas burned can be obtained from a few suppliers rather than from the thousands of users. Many times a short-cut method will supplement or serve as a check to a complete survey.

Another type of short cut is feasible when surveying an industry or operation composed of many companies with a relatively few companies responsible for the majority of the emissions. Where the extent of a particular industry or operation is known, it also may be possible to survey only a representative few of the companies concerned and extrapolate the results.

Utilization of Total Air Pollution Data

It should be realized that some contaminants which may be relatively innocuous in themselves are transformed wholly or partially by atmospheric reactions into other materials of an annoying or detrimental nature. Also, meteorological conditions influence the degree of contaminant dispersion and kinetics of atmospheric reactions. Total air pollution figures, therefore, cannot always be construed as direct measures of the amount of "smog" present in the atmosphere. They do, however, serve to focus attention on the possibility of adverse atmospheric reactions and attendant air pollution effects.

The APCD utilizes data obtained in total air pollution studies as one of the bases for recommending and substantiating legislative and administrative actions. Data obtained from the studies assist the control officer in determining:

1 The contribution to the total problem of each industrial, commercial, and domestic activity.
2 The contribution to the total problem of each chemical species emitted.
3 Hourly, monthly, and yearly variations in emission rates.
4 Variations of emissions with geographical location.
5 Correlations of emission data with air monitoring and meteorological data.
6 Most effective future control measures.
7 Effects of control measures instituted.

Presentation of Total Air Pollution Data

The effect and utility of total air pollution emission estimates would be wasted if they were not brought to the attention of control program directors, the public, and concerned industry in a clearly understandable manner. There are many ways of presenting total air pollution emission data to attain these objectives.

The APCD usually reports the information as average daily tonnages of the various air contaminants emitted from industrial, commercial, and domestic activities. For special purposes, estimates of maximum or peak daily emissions have been made. It has also been very revealing to prepare estimates for specific seasons, hours or other designated periods, for specific geographical areas, and for specific activities or groups of activities.

To appraise the public and others in a simplified, graphic fashion, total air

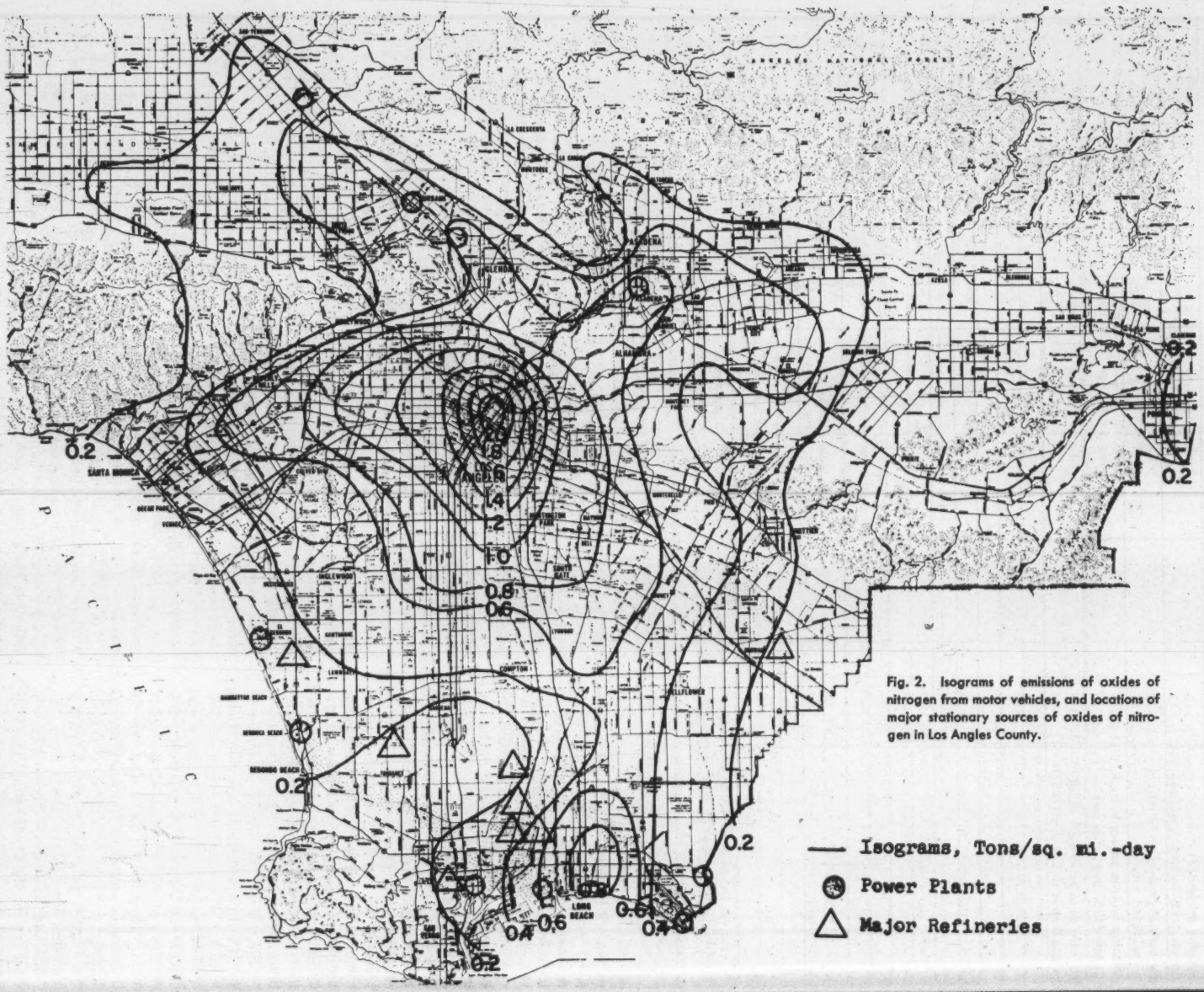

Fig. 2. Isograms of emissions of oxides of nitrogen from motor vehicles, and locations of major stationary sources of oxides of nitrogen in Los Angles County.

Table III—Emissions of Air Contaminants from Gasoline- and Diesel-Powered Vehicle Exhausts in Los Angeles County

Type of Vehicle[a]	Emissions in Tons per Day						
	Hydrocarbons	Aldehydes and Ketones	Other Organic Gases	Carbon Monoxide	Oxides of Nitrogen	Sulfur Dioxde	Aerosols
Automobiles	740	9	12	6850	250	20	24
Buses and trucks	270	3	4	2000	95	8	9
Buses and trucks (diesel-powered)	4	*n*	*n*	3	4	1	1
Totals (rounded)	1000	12	15	8850	350	30	35

[a] All vehicles gasoline-powered unless otherwise specified.
[b] Includes blow by emissions but not evaporation losses from fuel tanks and carburetors.
n—Less than 0.5 ton per day.

pollution emissions for all Los Angeles County sources are reproduced on a $3^1/_2$ in. × $4^1/_2$ in. wallet-size card. A 7 ft × 20 ft display board has been constructed at APCD headquarters so that all visitors may see at a glance the current values. The card bears, in addition to average daily tonnages of emitted air contaminants, associated information such as maximum concentrations of air contaminants measured, number of "alerts" declared, motor vehicle registration and fuel consumption, and typical automobile exhaust gas measurements. The display board presents total air pollution emissions from each type of operation and category of industry. In addition, the emissions of important contaminants are listed by source. This system facilitates the abstraction of special totals for contributions of specific industries, operations common to many industries, or major sources of each contaminant.

For special treatment where indicated, total air pollution data are plotted on area maps. Figure 2[1] is an example of this usage of maps. From these, an over-all view of contaminant source locations and area rate emissions are obtained.

Emissions from Vehicle Exhausts

In the category of vehicle exhausts are included the air contaminants emitted through the exhausts of gasoline-powered vehicles (automobiles, trucks,. buses), diesel-powered vehicles (truck, buses, railroad locomotive engines, ships) as well as vehicles powered by other fuels.

The majority of the total average daily tonnages of air contaminants emitted into the Los Angeles atmosphere is from gasoline-powered vehicles. Table III shows the comparative daily tonnages of the contaminants emitted from gasoline- and diesel-powered vehicles.

The quality of combustion is considerably better in a diesel engine than in a gasoline engine. For this reason only about 0.3 percent of the total contaminants emitted from vehicle-exhausts (excluding carbon monoxide) are from diesel-powered vehicles even though one percent of the total fuels used for vehicular transportation is used in diesel trucks and buses. The contribution of air contaminant emissions from aircraft and railroad engines in Los Angeles County is very small compared to road vehicles. The fuel oil burning steam locomotive, as a thing of the past in Los Angeles County, adds no pollution.

Determination of emission rates from vehicles is very difficult and has been the subject of considerable research within the last five years. In arriving at total air pollution emission values from vehicle operation, determination of average driving, and average engine conditions must be made for an "average" model and make of vehicle.

Considerable work has been done by the APCD Automotive Combustion Laboratory on this problem. Studies were made of traffic volume and flow during various hours of the day. Conferences were held with other governmental agencies concerned with traffic engineering so that typical driving routes could be determined. Freeway, main arterial business and residential streets were incorporated in the mapped routes to insure that average driving conditions in the County would be realized.

Driving habits of some 80 individuals were recorded by instruments over selected composite routes during peak and off-peak traffic hours. The percentages of time spent in the various driving cycles (idle, cruise, acceleration, and deceleration) were computed. From this large group of drivers certain individuals were found to possess driving habits representative of the group as a whole. These drivers were then used in further surveys.

Some of the objectives of this driver survey were to determine an over-all weighted breakdown of time spent in various driving cycles, comparison of standard and automatic transmission performance, study of traffic density effects, and comparison of routes. Samples of exhaust gas effluents during the various cycles of engine operation were collected and analyzed. Correlation of these analytical results with percentages of time spent in the various driving cycles, number of vehicles, type of operation, and gasoline consumed provided the bases for calculating the quantities of various air contaminants emitted from automobiles. Combined with meteorological observations and traffic volume and flow, the degree of the contribution of automobiles to the air pollution problem was made apparent.

The APCD Automotive Combustion Laboratory has been able to accelerate and implement the road testing program through the use of stationary engines and dynamometers by which various driving conditions are simulated. Figure 3 shows a typical test in progress. Exhaust gases from a stationary engine are being vented through an after burner device and samples of the exhaust gases are being collected for analysis. At the present time, direct reading instruments are being used to measure concentrations of hydrocarbons and carbon monoxide exhausted from internal combustion engines. Grab samples are analyzed for oxides of nitogen, aldehydes, etc.

Many times the APCD is called upon to evaluate ideas, suggestions, or proposals involving the substitution of different type fuels for gasoline or different types of propulsion systems. Tests for emissions of air contaminants are also made to verify opinions based on incomplete data or theoretical considerations.

Illustrative of certain difficulties encountered in evaluating automobile exhaust emissions are the considerable variations in concentrations of nitrogen oxides and other exhaust contaminants that have been found between automobiles of like make, model, and year. To add to the difficulties, sampling and analytical techniques to measure average concentrations during each driving cycle were not as sensitive or precise as desired, although instrumentation has been improved recently.[2] Table IV contains values obtained from measurements of a typical automobile exhaust gas.

Chass and Dickinson[3] discussed the calculations of air contaminant emissions

Fig. 3. Stationary engine and associated equipment used by APCD Automotive Combustion Laboratory in investigation of automobile exhaust gas effluents and efficiencies of control methods.

from gasoline-powered vehicles from the exhaust and from evaporation from carburetors. Emissions from passenger car exhausts of C_3 or heavier hydrocarbons, acetylene, aldehydes and ketones, other organic gases, carbon monoxide, and oxides of nitrogen were calculated from APCD test data by the following equations:

1 For each driving cycle

$$T = \frac{C \times A \times V \times G}{(379)(2000)}$$

where

T = tons of the contaminant emitted per day by the group of vehicles during the operating cycle or condition under consideration,

C = average concentration (in ppm by volume, dry basis, standard conditions) for the contaminant and operating cycle under consideration,

A = molecular weight of the contaminant,

V = average volume of exhaust gas (in standard cubic feet, dry basis) per gallon of fuel burned during the operating cycle under consideration,

G = volume of gasoline (in millions of gallons per day) burned in Los Angeles County by the group of vehicles and during the operating cycle or condition for which the calculation is being made.

2 For the total quantity (ΣT) of the contaminant emitted per day during normal operation of the group of vehicles under consideration,

$$\Sigma T = T_I + T_A + T_C + T_D$$

where

T_I = quantity of the contaminant emitted per day during idling,

T_A = quantity of the contaminant emitted per day during acceleration,

T_C = quantity of the contaminant emitted per day during cruising,

T_D = quantity of the contaminant emitted per day during deceleration."

The necessary data for calculating total gasoline consumption per day in Los Angeles County is obtained from the State Board of Equalization and Department of Motor Vehicles. Vehicle registration (excluding trailers and motor cycles) is used to prorate gasoline consumption in Los Angeles County from state gasoline consumption figures.

As of December 31, 1958, there were approximately 2,930,000 motor vehicles registered in Los Angeles County. The daily average gasoline consumption during 1958 was approximately 5,820,000 gallons.

Exhaust gases contain methane, ethane, ethene, and acetylene in such quantities that they cannot be ignored in any consideration of contaminant emissions from gasoline-powered vehicles. Methane and acetylene in exhaust gases are calculated from APCD test data. On the basis of work by Hurn[4] showing the ethane content of exhaust gas to be quite low, ethane and ethene emissions were considered as one fraction and the total emissions calculated as ethene.

Emissions of sulfur dioxide in vehicular exhaust are calculated from data

Table IV—Typical Automobile Exhaust Gas Measurements

Variables Measured[a]	Driving Cycle			
	Idle	Acceleration	Cruise	Deceleration
Hydrocarbons, average (as hexane), ppm	800	400	375	3500
Acetylene, average, ppm	710	170	178	1096
Aldehydes, average, (as formaldehyde), ppm	15	27	34	199
Nitrogen oxides, average, (as nitrogen dioxide), ppm	23	1100	900	6
Carbon monoxide, average, percent by volume	5.0	4.3	3.5	4.0
Carbon dioxide, average, percent by volume	10.2	12.1	12.4	6.0
Oxygen, average, percent by volume	1.8	1.5	1.7	8.1
Exhaust gas volume, average, scfm	8	60	35	8
Exhaust gas volume, range, scfm	5–25	40–200	25–60	5–25
Exhaust gas temperature, range, °F	300–400	1000–1100	600–700	400–900
Average driving time, percent	19	19	37	25

[a] In addition, there will be found varying amounts above one percent, by volume, of water, nitrogen, and hydrogen; there also will be minute amounts of sulfur oxides, organic acids, alcohols, and particulate matter.

Table V—Emission of Air Contaminants Into Los Angeles County Atmosphere from Combustion of Fuels

Source	Emissions, Tons per Day[a]							
	Hydrocarbons	Aldehydes and Ketones	Other Organic Gases	Oxides of Nitrogen	Oxides of Sulfur	Carbon Monoxide	Other Inorganic Gases	Aerosols
Liquid fuels								
Power plants	1	1	2	130	240	*n*	*n*	19
Refineries	1	*n*[b]	2	10	40	*n*	*n*	3
Other industries	*n*	*n*	*n*	20	60	*n*	*n*	6
Domestic and commercial	*n*	*n*	*n*	5	17	*n*	*n*	1
Gaseous fuels								
Power plants	0	*n*	*n*	55	*n*	*n*	*n*	1
Refineries	4	*n*	3	40	40	1	*n*	4
Other industries	0	*n*	*n*	12	*n*	*n*	*n*	1
Domestic and commercial	0	0	0	25	*n*	*n*	*n*	5
Totals (rounded)	6	1	7	300	400	1	*n*	40

[a] During months when Rule 62 is not in effect.
[b] *n*, Negligible, less than 0.5 ton per day.

on gasoline sulfur contents given by U. S. Bureau of Mines National Motor Gasoline Surveys and other sources. The average sulfur content, by weight, of regular gasoline sold in Southern California during 1957 was 0.192 percent and of premium gasoline, 0.095 percent. Oxides of nitrogen and particulate matter emissions in exhaust gases are calculated from the concentration levels and exhaust gas volumes determined by testing.

Emissions from Combustion of Liquid and Gaseous Fuels

The combustion of liquid and gaseous fuels in boilers, heaters, and other process equipment is a major source of aerosols, oxides of nitrogen, and sulfur dioxide emissions to the Los Angeles atmosphere. However, tests show that emissions of hydrocarbons, other organic materials, and carbon monoxide from properly operated combustion equipment are extremely low. A manifestation of the emissions from certain fuel oil burning installations is a visible plume, but, generally, this occurs only at the largest installations or at installations burning high sulfur fuel. Smoke due to poor operation is almost extinct from stationary combustion sources in Los Angeles.

The principal fuels for stationary combustion equipment are liquid fuel oils, ranging from heavy residual fuels to diesel oils, natural gas and refinery make gas. Liquefied petroleum gases (LPG) are also burned as boiler and heater fuel but only in small quantities. The APCD reports emissions separately for liquid fuels and gaseous fuels and further apportions the emissions for each into the major sources: power plants, refineries, other industrial boilers and heaters, and domestic and commercial sources. Table V shows actual quantities of contaminants emitted from the burning of fuels in Los Angeles County.

Aerosols and sulfur dioxide emissions are related to the composition of the fuel whereas emissions of oxides of nitrogen result from the fixation of oxygen and nitrogen in the combustion air and are dependent upon combustion temperatures, rates of cooling, and equipment characteristics. The emissions of each of the above contaminants are derived from the product of average contaminant emission factors and fuel usage. Contaminant emission factors have been obtained from the results of more than 200 stack tests by the APCD on power plant boilers and other fuel oil burning equipment and are shown in Table VI. Fuel oil usage figures are obtained from U. S. Bureau of Mines monthly "Petroleum Demand" reports and by actual surveys of fuel oil users. Oil refineries, power plants, and other large industrial users submit on a regular monthly basis the quantities of fuel oil consumed. Natural gas usage is obtained from natural gas suppliers and supplemented by surveys of selected users. Refinery make gas usage is furnished directly by the refineries concerned.

Since the adoption of Rule 62* large consumers of fuel submit to the APCD statistics on daily fuel usage. Rule 62 was promulgated for the sole reason of requiring the maximum possible usage of natural gas. As all emission factors for natural gas are considerably lower than for fuel oil, total air pollution emissions will be reduced correspondingly during the effective periods of Rule 62.

George and Holmes[5] presented a re-

* Rule 62 of the Rules and Regulations of the Los Angeles County Air Pollution Control District prohibits the burning of liquor or solid fuels having a sulfur content in excess of 0.5 per cent by weight and the burning of gaseous fuels containing sulfur compounds in excess of 50 grains per 100 cubic feet, calculated as hydrogen sulfide, from May 1, 1959 to September 30, 1959 and from May 1 to October 31 each year thereafter.

Table VI—Emission Factors for Air Contaminants Discharged from the Combustion of Fuels in Stationary Sources

Location of Stationary Combustion Source	Emission Factors, Pounds per Thousand Equivalent Barrels of Fuel Oil Burned							
	Hydrocarbons	Aldehydes and Ketones	Other Organic Gases	Oxides of Nitrogen	Sulfur Dioxide	Carbon Monoxide	Other Inorganic Gases	Aerosols
Power plants								
Gaseous fuels	*n*[b]	6	18	4020	2.5	*n*	*n*	90
Liquid fuels	33.9	24.9	114.2	6070	11,000	1.79	*n*	893
Refineries								
Gaseous fuels	156	18	84	1380	2.5[a]	25	*n*	126
Liquid fuels	146	26.8	473	2930	11,500	*n*	*n*	821
Other industries								
Gaseous fuels	*n*	12	30	360	2.5	2.4	*n*	105
Liquid fuels	31.6	25	70.6	2860	8,050	6.25	*n*	839
Domestic and commercial								
Gaseous fuels	*n*	*n*	*n*	300	2.5	2.4	*n*	112
Liquid fuels	27.9	22.1	62.2	2520	7,425	*n*	*n*	593

[a] Does not include emissions from the burning of refinery make gas.
[b] *n*, negligible, traces only.

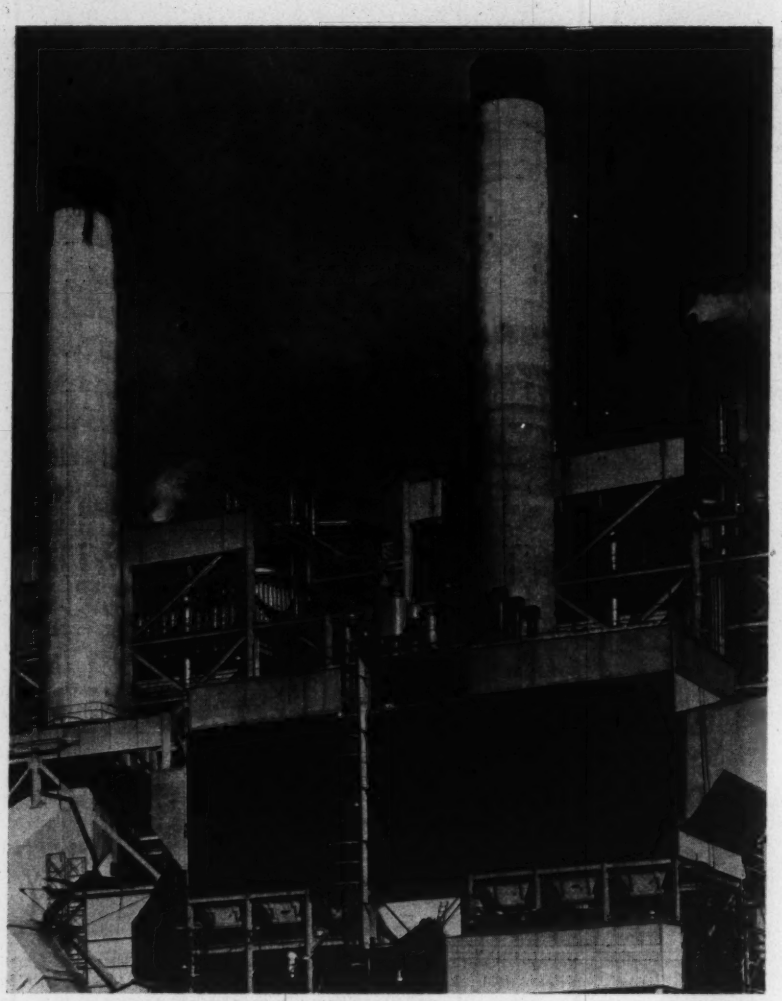

Fig. 4. Electrical precipitator installed to reduce opacity of plume from oil-fired steam-electric generating power plant.

view of the air pollution problems from the combustion of fuels concurrently with information of interest on total air pollution emissions. According to this report, steam-electric generating power plants were the largest industrial users of both fuel oil and natural gas. They consumed more than twice the quantity of fuel oil used by all other industrial customers and approximately ten times as much fuel oil as that used by the refineries. Metallurgical operations and the drying and calcining of other materials account for much of the "other industrial" fuel usage. In metallurgical operations, fuel oil or gas is generally used.

During peak period usage, the power plants consumed nearly four times as much fuel oil as all other interruptible customers of natural gas suppliers. Practically all commercial and small industrial establishments, and the majority of large industrial plants, use natural gas with fuel oil only for standby.

There are eleven steam-electric generating plants and an estimated 17,000 industrial establishments operating with in the boundaries of Los Angeles County. Power plants and industrial units collectively consume fuel oil in amounts varying from 60,000 to 100,000 equivalent barrels per day, resulting in daily emissions to the atmosphere of 700 to 1100 tons of various air contaminants.

Visible stack plumes from power plants burning fuel oil can persist and extend for many miles, depending upon weather conditions. Besides spreading air pollution over a wide area, plumes may also bring heavy contaminant concentrations to ground level at areas downwind from the plants. Heavy local concentrations have, in fact, occurred and resulted in damage to vegetation and in soot problems.

The direct control of power plant air pollution emissions in the Los Angeles area is being approached from four directions: (1) substitution of natural gas for fuel oil, (2) treatment of the fuel, (3) boiler modification, and (4) treatment of the effluent. No practical means have yet been devised to remove, before burning, the elements in the fuel which cause contamination. Investigations initiated by private enterprise indicate that an appreciable reduction in oxides of nitrogen can be attained by boiler modification. A full scale electric precipitator has been installed by Southern California Edison Company at its local El Segundo steam station (Fig. 4) after extensive pilot plant studies, but its effectiveness has not yet been verified by APCD stack tests.

Emissions from Evaporation of Organic Liquids

Responsible for a substantial tonnage of organic emissions in the Los Angeles area, second only to automobile exhaust, is evaporation of organic liquids. Evaporation occurs principally in tanks storing crude oil, petroleum distillates, solvents, and other chemicals, in carburetors, and in the application of coatings and adhesives containing volatile organic liquids. Hydrocarbons constitute the gratest part of the emissions, but, in the case of solvents and diluents contained in protective coatings, about 25 percent of that evaporated is made up of ketones, alcohols, and esters. Table VII shows emissions of organic vapors in Los Angeles County from the many sources from which the process of evaporation occurs.

Storage and Loading

Storage tank emissions occur by "breathing out" of the vapors from the vessel and displacement of vapors during filling operations. Individual storage containers range from underground reservoirs with capacities in the millions of gallons to carburetors on automobiles with capacities in ounces. Emissions

Table VII—Emissions from Evaporation of Organic Liquids in Los Angeles County

Source	Organic Vapor Emissions, Tons per Day
Storage and loading	200
Automobile carburetors and fuel tanks	25
Organic solvent usage	435
Total (rounded)	660

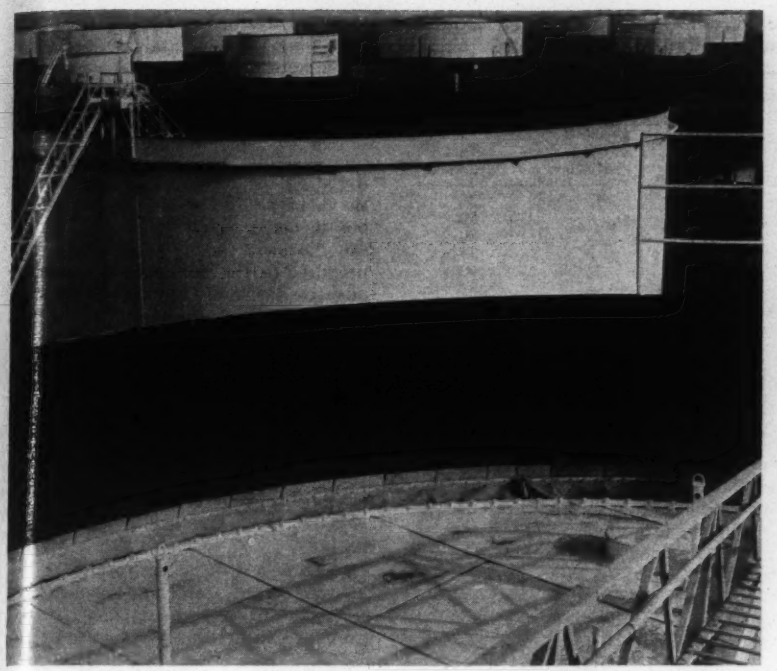

Fig. 5. Storage tanks equipped with floating roof controls.

Fig. 6. Vapor closure on tube for loading petroleum product into a tank truck. The vapor closure prevents vapors from being emitted through the tank truck hatch and routes them through a vapor return line to a vapor control system.

from reservoirs are generally insignificant because of the low volatility of the stored product, usually a heavy residual fuel. Most of the storage capacity for crude oil and petroleum distillates is found in oil industry installations such as refineries, pipeline tank farms, marine terminals, bulk marketing terminals and plants, production fields, and retail service stations. In Los Angeles County, capacity for crude oil storage in the refineries alone amounts to more than 7,000,000 barrels, and capacity for light petroleum distillates amounts to more than 20,000,000 barrels.

During the last few years, the petroleum industry has carried out an extensive program to control the emissions of hydrocarbon vapors from storage facilities. They have utilized vapor recovery systems, vapor balancing systems, floating roof tanks (Fig. 5), and pressure storage tanks. It is estimated that this program has resulted in the reduction of more than 250 tons of hydrocarbon emissions daily. Emissions of hydrocarbon vapors from storage containers operated by the petroleum industry have been calculated by methods presented at an American Petroleum Institute symposium.[8] With some modifications, these methods of calculations can be used for similar products.

Refinery and bulk marketing terminal tank truck loading operations are controlled in Los Angeles County[9] but probably nowhere else. Specialized equipment was developed by the oil industry to seal filling hatches, collect vapors displaced during filling (Fig. 6), and route these vapors to recovery or disposal systems. Package absorption units, using gasoline from storage as the absorbent, have been installed at bulk plant or other locations where flares, fuel gas systems, or tank farm vapor recovery systems are not practical or accessible.

Automobile Carburetors and Fuel Tanks

In recent publications,[3, 10] emissions from automobile carburetors and fuel tanks are described. The mechanisms whereby contaminants are emitted to the atmosphere and their quantities calculated are included in these reports. Information from an earlier paper by Wentworth[11] was applied in computing evaporation loss emissions from the carburetor during operation and during the "hot soak" period.*

Evaporation emissions from automobile fuel tanks are based upon APCD test results which indicate that average emissions per tank are 0.045 pounds per day.

Organic Solvent Usage

A comprehensive survey has been conducted of organic solvent usage in Los Angeles County. A report by Lunche, et al.[12] presents the many categories of industrial sources and operations responsible for the bulk of organic solvent vapor emissions.

Individual surveys have been made on solvent usage and practices in several categories of industry; for example, automobile assembly, metal can and container manufacturing, aircraft, appliance manufacturing, protective coating manufacturing, dry cleaning, furniture manufacturing, printing, and rubber and plastic products manufacturing. As a supplement and check on the figures furnished by these industries, a survey was made of solvent sales and distribution to Los Angeles County buyers by solvent manufacturers and suppliers. In each of the industries surveyed, information was obtained on the operations in which solvents were used. Due to the nature of the solvent and its purpose in industrial operations, almost all of the solvent which is used eventually evaporates into the atmosphere. Thus, the quantities of solvent vapor emissions can be equated to the fresh solvent usage. Tables VIII and IX give solvent emissions in Los Angeles County from various operations and industries.

Generally, control of solvent vapor emissions has not been practiced because of the dilute concentration of solvent in the effluent gases from the operation involved. Recently, installations of controls for some solvent vapor emissions have been made.[13] Control methods used are direct flame incineration, catalytic incineration, adsorption, scrubbing, and condensation. How-

* The first half hour after cessation of engine operation. During this period, the heat dissipated from the engine volatilizes some gasoline from the carburetor.

Table VIII—Emissions of Organic Vapors from Operations Using Organic Solvents in Los Angeles County

Type of Operation	Organic Vapor Emissions, Tons per Day: Hydrocarbons	Halogenated Hydrocarbons	Oxygenated Hydrocarbons	Totals (rounded)
Surface coating	190	*n*[a]	45	235
Degreasing	20	40	*n*	60
Dry cleaning	20	8	*n*	30
Rotogravuring	10	*n*	3	18
Other	60	*n*	35	95
Totals (rounded)	300	50	85	435

[a] *n*, negligible, less than 0.5 ton per day.

ever, the amount of solvent vapor emissions controlled is small relative to the total quantity of solvent emissions.

An engineering development project and a usage survey supported by demonstration grants from the U. S. Public Health Service have been initiated. The engineering development project has the objective of evolving feasible methods of controlling organic emissions from protective coating spraying and baking operations. At the present time, adsorption of organic solvent vapors upon activated charcoal is the approach being pursued, as this method appeared more promising from a study[14] than many other different methods of control. Results of these studies will provide data on efficiencies of various control systems and will be useful for total air pollution estimates. The equipment and procedures selected for the first experimental control development project are described by Spencer, et al.[15]

Emissions from Petroleum Refining and Chemical Processing

An intensive investigation of emissions from petroleum refining activities in Los Angles County has recently been completed as a joint project of the Los Angeles County Air Pollution Control District, United States Public Health Service, State of California Department of Public Health, and the Western Oil and Gas Association. This investigation relied heavily upon a source testing program. Individual reports covering the contaminant sources in refineries have been published and a summation of all findings has been made in a final report.[7] In addition to the Joint Project findings, total air pollution emission estimates for refinery sources are revised periodically by the APCD using results from a yearly survey of hydrocarbon emissions of the oil refineries, a semiannual survey of sulfur dioxide emissions of the oil refineries, and scavenger-type chemical plants, monthly reports of fuel usage, from daily inspections performed by APCD inspectors and from data on permits issued for new and modified equipment.

Table X shows numerical values of emissions from petroleum refining and chemical processing operations other than storage and combustion of fuels, already reported in Table V and VII. The quantities given in Table X are based, as much as possible, upon test results, and where test results were unobtainable, upon evaluations using the best information available. Table XI gives hydrocarbon emission factors for petroleum refining sources.

A prominent source of air pollution in local refineries is the catalyst regenerator used in the catalytic cracking process. Contaminants emitted directly from regenerators are carbon monoxide, hydrocarbons, oxides of nitrogen, oxides of sulfur, catalyst dust, and a visible plum. The catalyst promotes cracking of heavier petroleum products into lighter petroleum products and accumulates deposits of coke and sulfur during the cracking reaction. In order to regenerate the catalyst it is transferred to the regenerator vessel where the deposits are burned, producing carbon monoxide, carbon dioxide, and sulfur dioxide. Oxides of nitrogen are produced by the fixation of atmospheric nitrogen during the combustion process. Catalyst dust is entrained in exit gases.

About one-fifth of all carbon monoxide emitted into the Los Angeles atmosphere is discharged with the flue gases from catalytic cracking regenerators. The majority of this carbon monoxide originates with fluid-type units. No correlation has been established between carbon monoxide and any air pollution effect although its toxic nature is well known.

With regard to the hydrocarbons discharged from catalyst regenerators, it has been shown by many mass spectrographic analyses that 90–95 percent are methane and ethane which have not been shown to be significant in the production of air pollution effects.

Emissions of carbon monoxide and hydrocarbons are considerably reduced in quantity by waste heat boilers. These waste heat boilers burn the carbon monoxide and hydrocarbons to carbon dioxide and water, and take advantage of the heat released by combustion to generate steam for refinery purposes. Two out of the six fluid catalytic cracking units in Los Angeles County are now equipped with waste heat boilers and construction of a waste heat boiler for a third unit is almost complete. Companies operating two of the remaining fluid units have indicated their intention to install or investigate the installation of similar units.

In the circulation of catalyst, attrition creates exceptionally fine catalyst particles which are not collectible in the

Table IX—Organic Solvent Usage in Los Angeles County by Ultimate Consumers[a]

Type of Consumer	Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Halogenated Hydrocarbons	Alcohols Glycol Ethers	Ketones	Esters and Others	Totals (Rounded)
Automobile assembler	8	8	0	2	3	3	25
Aircraft manufacturer	6	8	10	2	5	1	30
Dry cleaner	20	*n*[b]	8	0	0	0	30
Rubber and plastic product manufacturer	15	2	*n*	3	4	*n*	25
Furniture manufacturer	3	4	0	1	1	1	10
Metal container manufacturer	1	1	0	1	5	*n*	10
Pharmaceutical and cosmetics manufacturer	*n*	0	0	10	2	0	10
Auto repair	1	2	*n*	*n*	1	*n*	5
Printers	4	4	0	1	1	1	10
Other activities	160	50	30	20	25	5	290
Totals (rounded)	215	80	50	40	45	10	445

[a] Does not include repackagers or manufacturers of products containing solvents.
[b] *n*, negligible, less than 0.5 tons/day.
[c] Based on 30-day month.

Table X—Emissions of Air Contaminants to the Atmosphere from Petroleum Refining and Chemical Processing in Los Angeles County

Source	Emissions of Air Contaminants, Tons per Day[a]							
	Hydrocarbons	Aldehydes and Ketones	Other Organic Gases	Oxides of Nitrogen	Oxides of Sulfur	Carbon Monoxide	Other Inorganic Gases	Aerosols
Refinery:								
Catalytic cracking regenerators	11	2	*n*[b]	5	30	70	4	5
Separators and sewers	2	0	0	0	0	0	0	
Treating	*n*	0	0	0	0	0	0	0
Relief valves	2	0	0	0	0	0	0	0
Pump glands	6	0	0	0	0	0	0	0
Blowdown, turnarounds, vessel and tank maintenance	2	0	0	0	0	0	0	0
Cooling towers	3	0	0	0	0	0	0	0
Compressor exhaust[c]	7	—	—	5	—	—	—	—
Valves and flanges	10	0	0	0	0	0	0	0
Compressor glands	1	0	0	0	0	0	0	0
Miscellaneous refinery equipment	4	0	0	0	21	0	0	0
Chemical:								
Sulfur and sulfuric acid	0	0	0	0	45	0	0	0
Other chemical	16	8	16	*n*	1	*n*	1	3
Total (rounded)	65	10	15	10	75	700	5	10

[a] Does not include emissions of air contaminants from burning of fuels and storage of petroleum products.
[b] *n*, negligible, less than 0.5 ton per day.
[c] Tested only for hydrocarbons and oxides of nitrogen.

usual internal cyclone system of catalyst regenerators. Rule 54 of the APCD Rules and Regulations requires that emissions of this type be limited in accordance with the process weight; thus, highly efficient dust control equipment has been installed for each of the local catalytic cracking units. Electrical precipitators are used for fluid catalytic cracking units and centrifugal type collectors are usually used for the thermofor catalytic cracking units.

The detached, persistent, opaque plume which forms on certain occasions from the exit gases of the catalytic regenerator is a difficult air pollution problem. Its formation appears to depend upon temperature and humidity. Complete agreement as to the mechanism of its formation, or its composition, has not been attained. Fortunately, the use of waste heat boilers prevents the formation of such a plume almost 100 percent of the time.

Other major sources of refinery emissions in Los Angeles County are also controlled. For example, oil-water effluent separators are now covered with floating roofs or are vented to recovery systems. Flares for burning waste gases have been made nearly smokeless in operation by redesign incorporating steam injection (Fig. 7) or a "step-up pressure" series of venturi burners.

Table XI—Hydrocarbon Emission Factors for Petroleum Refining Sources

Sources of Emission	Hydrocarbon Emission Factors Pounds per 1000 Barrels Crude	
	Uncontrolled	Controlled
Crude oil storage	500	75
Petroleum distillate storage	670	100[a]
Fluid catalytic cracking	200	12[b]
Thermofor catalytic cracking	50	—
Separators	270	8
Valves and flanges	28	—
Pump seals	125[c]	20[d]
Relief valves	80	5
Loading racks	150[e]	2[e]
Vacuum jets	150	0
Blowdowns, turnarounds vessel and tank maintenance	25	5
Treating	8	2
Cooling towers	6[g]	—
Compressor exhausts	1[h]	—
Miscellaneous	50	12

[a] Floating roof controls. For vapor recovery, factor would theoretically be zero.
[b] Controlled by carbon monoxide waste heat boiler.
[c] Mostly packed gland seals.
[d] Mechanical seals for light hydrocarbon service.
[e] Pounds per 1000 barrels loaded.
[f] Controlled by condensation and incineration of non-condensables.
[g] Pounds per 1,000,000 gal of cooling water.
[h] Pounds per 1000 cf of gas burned.

Many packed-gland type pumps in light hydrocarbon service have been converted to mechanical-seal type pumps. Addition, revision, and expansion of hydrogen sulfide absorption equipment has removed hundreds of tons of hydrogen sulfide from refinery gases. The hydrogen sulfide is shipped to scavenger plants for conversion into elemental sulfur or sulfuric acid. By this means, as much as 600 tons per day of sulfur dioxide is prevented from entering the Los Angeles atmosphere.

Emissions from the major petrochemical plants, which in Los Angeles County manufacture styrene, butadiene, synthetic rubber, polyethylene and oxygenated solvents, are quite low, about one ton per day. These plants are well controlled by extensive recovery and flare systems. Emissions from other chemical processing in Los Angeles County are relatively insignificant.

Emissions from Incineration of Combustible Refuse

Prior to October, 1956, approximately 11,000 tons of combustible refuse were burned in open fires and single chamber incinerators in Los Angeles County. Open fires, with few exceptions, are now illegal in the Los Angeles Basin. These exceptions allow for training personnel in fire fighting duties and for limited agricultural operations. The use of single chamber incinerators has been banned in the Los Angeles Basin since September 30, 1957. At present, most combustible refuse is buried in land-fill dumps, and the remainder is burned in municipal incinerators or approved multiple chamber type incinerators. Incinerator design standards for meeting APCD rules have been set forth by Williamson and Twiss.[16]

Table XII—Emissions of Air Contaminants from Burning Combustible Refuse in Los Angeles County, in Tons per Day

Contaminant	Emissions Prior to Ban on Open Fires[a] and Single-Chamber Incinerators[b]	Emissions after Ban on Open Fires[a] and Single-Chamber Incinerators[b]
Hydrocarbons	35	*n*[c]
Aldehydes and ketones	55	*n*
Other organic gases	40	4
Oxides of nitrogen	25	3
Sulfur dioxide	20	1
Carbon monoxide	175	4
Other inorganic gases	*n*	*n*
Aerosols	80	4

[a] Rule 57 of the Rules and Regulations of the Los Angeles County Air Pollution Control District prohibits the burning of combustible refuse in the Los Angeles Basin after September 30, 1957 except for certain acts of fire hazard prevention, fire fighting training, and agricultural operations.

[b] Rule 58 of the Rules and Regulations of the Los Angeles County Air Pollution Control District prohibits the burning of combustible refuse in any incinerator within the Los Angles Basin except in an approved multiple-chamber incinerator or its equivalent.

[c] *n*, negligible, less than 0.5 ton/day.

Table XII compares the emissions from the incineration of combustible refuse before and after the single chamber incinerator and open fire ban went into effect. These emissions are based upon test data for many incinerators.

Emissions from Metallurgical Processing

Emissions of air contaminants from the metallurgial industry operations in Los Angeles County are generated from metal melting and pouring, molding, core baking, grinding, fabricating, plating, etc. These emissions consist mainly of aerosols.

Table XIII which gives emissions of aerosols from all measurable sources indicates that about six percent of the total aerosols discharged into the Los Angeles atmosphere are emitted as a result of metal melting operations. The aerosols emitted from metal grinding, polishing, fabrication, etc., are minor in terms of tons per day and, in addition, their relatively large size enables them to settle rapidly and not be dispersed into the atmosphere. Their removal from effluent gases is also facilitated by their size. For the large size aerosols, a simple centrifugal separator can effectively remove these particles. Baghouses and electrical precipitators are used in the main for control purposes, with water scrubbers used in some few instances. About 85 percent of the aerosol emissions attributed to the metal industry in Los Angeles County are produced from the nonferrous pyrometallurgical group.

Table XIII—Emissions of Aerosols in Los Angeles County

Source	Emissions, Tons per Day
Transportation:	
Automobiles	20
Buses and trucks	14
Incineration of combustible refuse	4
Combustion of liquid fuels	30
Combustion of gaseous fuels[a]	8
Organic solvent uses	3
Petroleum refining:[b]	
Catalytic cracking regenerators	5
Other	*n*[c]
Chemical industries:[b]	
Fertilizer	3
Other	5
Mineral industries:[b]	
Insulation	*n*
Glass and frit	2
Asphalt roofing	
Asphalt batching	1
Concrete batching	1
Metals melting industries:[b]	
Ferrous	
Steel	1
Iron	*n*
Nonferrous	5
Miscellaneous:[b]	
Wood processing	
Rendering	*n*
Grain and feed	1

[a] Includes emissions from burning of refinery gas.

[b] Does not include emissions due to burning of fuels.

[c] *n*, negligible, less than 0.5 ton per day.

Fig. 7. Smoke from a refinery flare with controls not operating. With steam injection control in operation, no visible smoke is emitted.

Emissions from melting of nonferrous metals vary greatly not only with the types of alloys melted but also with melting methods, furnace design, type of flux covers used, pouring methods, and cleanliness of metal melted. Baghouses have proved to be successful and effective in most cases where controls are required.

Table XIV gives emission factors for the industrial installations and operations emitting aerosols in Los Angeles County and indicates the losses that can be expected from melting of nonferrous metals in various types of furnaces, and what these emission factors would be if these sources were controlled. From available data, it appears that the greater the agitation of the surface of the molten metal the greater the discharge of air contaminants.

Emissions to the atmosphere from gray iron cupolas has been reduced from about 13 to 22 pounds per ton of metal melted before controls were installed to about 0.3 pound per ton after controls were installed; electric steel furnaces, from 3 to 21 pounds per ton to about 0.2 pound per ton; open-hearth steel furnaces, from about 18 pounds per ton of metal melted to about 0.4 pound per ton. Baghouses, electrical precipitators (Figs. 8 and 9) and furnace design changes (Fig. 10) are used to achieve the reductions in aerosol emissions.[17]

To determine the amount of ferrous metals melted, types of furnaces utilized, types of operations, and types of controls, APCD files were reviewed and questionnaires sent to all companies involved in metal processing in Los Angeles County. The operating data obtained were correlated with emission factors (see Table XIV) obtained from APCD source tests. The contribution

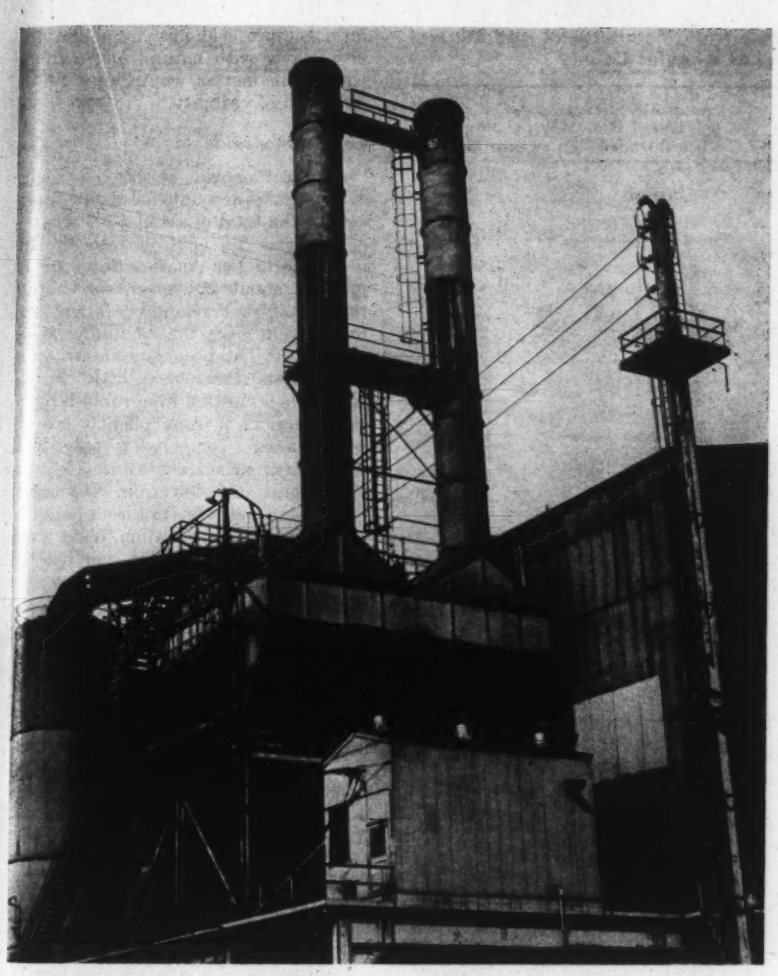

Fig. 8. Dust and fume emissions from 75-ton and 50-ton electric steel melting furnaces controlled by electrical precipitator.

of aerosols from the melting of metals for each type operation and installation and by the industry as a whole (Table XIII) were calculated.

Emissions from Mineral Processing Operations

The processing of minerals in Los Angeles County, which includes glass and frit manufacturing, concrete batching, asphaltic concrete batching, asphalt roofing, rock, sand, and gravel handling, etc., discharges about six percent of the aerosols emitted into the atmosphere from measurable sources (see Table XIII). A negligible amount of hydrocarbons is also emitted from such industries as glass manufacturing and asphalt roofing.

Many of the processes in the handling and manufacture of mineral products are such that simple centrifugal collectors or water wash systems (Fig. 11) can effectively control the amount of aerosols emitted. In some instances, such as perlite manufacturing, the size of particles emitted are extremely small and baghouse installations are necessary to provide adequate control to limits that would comply with the APCD Rules and Regulations. Table XIV shows emission factors used in obtaining estimates of aerosols discharged in Los Angeles County.

Nature of Contaminants Discharged

From the standpoint of public health, the most critical contaminant in the atmosphere of Los Angeles County is considered to be ozone. A very small amount of ozone comes from various electrical operations, but the great majority is believed formed as a result of atmospheric chemical reactions involving nitrogen oxides and organic gases in the presence of sunlight. None of the organic gases emitted are believed to be toxic by themselves in concentrations which have been attained in the open atmosphere.

Table XV shows the concentrations of ozone, oxides of nitrogen, oxides of sulfur, and carbon monoxide specified

Fig. 9. Four electrical precipitators, each preceded by a waste heat boiler, control emissions of dusts and fumes from four open hearth steel furnaces.

in the Los Angeles County statutes for the various "alert" levels. Ozone is the only contaminant of these four which has reached the first alert level concentration, and it has reached this level many times over widespread areas within the Los Angeles Basin. In certain limited areas, concentrations of the other contaminants have risen to significant fractions of the first alert level. It is not expected, however, that their concentrations will reach even the first alert levels over widespread areas in the foreseeable future.

Oxides of Nitrogen

Oxides of nitrogen serve a dual role in air pollution, being themselves toxic in relatively low concentrations, and also active in the ozone-forming reaction. For both of these reasons, it is considered important to reduce concentrations of oxides of nitrogen. Nitrogen dioxide (NO_2) is formed by oxidation of nitric oxide (NO) with oxygen. An undetermined amount of nitric acid aerosol is formed from further oxidation of nitrogen dioxide. The quantity of oxides of nitrogen emitted from combustion operations is dependent upon flame characteristics, configuration of the firebox and flue ways, and amount of excess air.

Oxides of Sulfur

The extent of sulfur dioxide and sulfuric acid mist discharged in combustion flue gases is, essentially, a function of the amount of sulfur in the material burned. About 70 percent of the sulfur dioxide emitted in Los Angeles County is from the burning of fuel oil or refinery gas and remainder is emitted from the burning of sulfur or hydrogen sulfide at sulfur and sulfuric acid plants, miscellaneous refinery operations, and from vehicles.

A small amount of sulfur dioxide is oxidized to sulfur trioxide in the flue gases or in the atmosphere, which immediately hydrates in the atmosphere to

Table XIV—Emission Factors for Aerosols from Metallurgical and Mineral Processing Operations in Los Angeles County

Source	Aerosol Emission Factor, Pounds per Ton of Raw Material Processed Uncontrolled	Controlled
Hot asphaltic concrete plants	5	0.45
Perlite and vermiculite furnaces	21–88	—
Glass furnaces (recuperative)	3.4	—
Frit manufacturing furnaces	9.4	0.19
Open Hearth steel furnaces (58-ton capacity)[a]	17.8	0.36
Gray iron melting cupolas (average)	17.1	0.26
Less than 48 in. I.D.	12.9	—
48–60 in. I.D.	19.5	—
Greater than 60 in I.D.	18.9	—
Electric steel melting furnaces (average)	8.6	0.17
Less than 5 ton capacity	10.6	—
5-20 ton capacity	5.7	
50–75 ton capacity	9.6	—
Melting of red brass:		
Crucible or pot furnaces	3.3	—
Rotary furnaces	21.3	10.1[b]
Reverberatory furnaces	16.8	—
Electric furnaces	3	—
Melting of yellow brass:		
Crucible furnaces	14	5.1[b]
Rotary furnaces	—	22.8[b]
Reverberatory furnaces	—	5.7[c]
Electric induction type furnaces	0.7	—
Melting of bronze:		
Crucible furnaces	3.8	—
Rotary furnaces	30.6	4.7
Melting of aluminum:		
Crucible furnaces	1.9	—
Reverberatory furnaces	5.2	2.1

[a] Principally scrap remelt.
[b] Using slag cover as the only control method.
[c] With baghouse control.

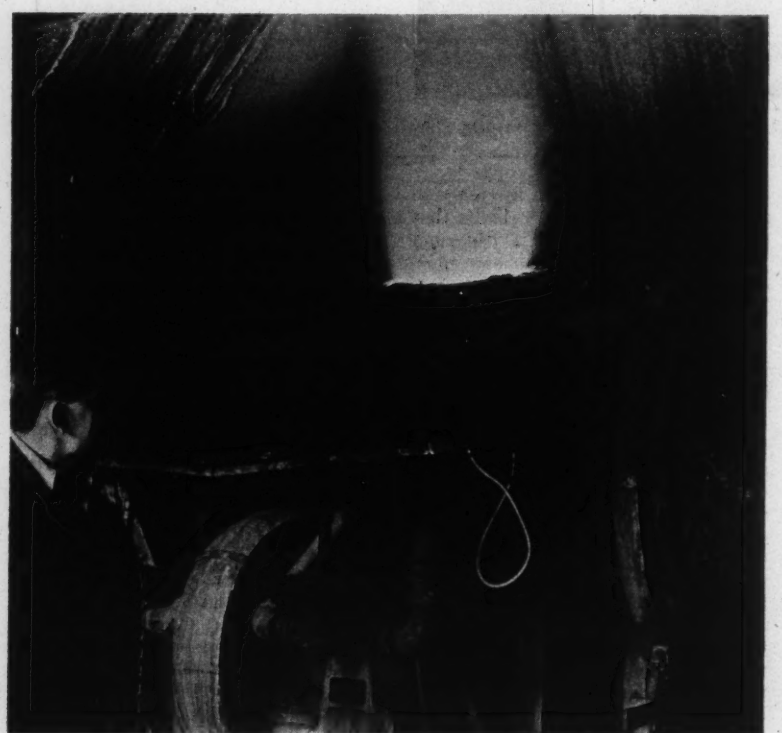

Fig. 10. A reverberatory gray iron melting furnace. The operation of this furnace does not produce emissions in excess of APCD standards.

form sulfuric acid mist. Sulfuric acid mist, along with natural and artificial particulate matter, contributes to the reduction of visibility.

Carbon Monoxide

Carbon monoxide in gasoline engine exhaust gases accounts for about 75 percent of the total of about 5500 tons per day of this gas emitted into the atmosphere of Los Angeles County. At present, about 20 percent is emitted from catalytic cracking operations and five percent from the metallurgical industry. It has been determined from many tests that very little carbon monoxide is emitted from rubbish burning operations or from boilers or heaters in this area. Compared to other contaminants, carbon monoxide is by far the largest emission from a tonnage standpoint, but it has not been found to be a factor in eye irritation, plant damage or visibility reduction, nor has the concentration of carbon monoxide yet reached a toxic level in the open atmosphere.

Aerosols

Aerosols in liquid and solid form are emitted from a large variety of sources within Los Angeles County. Aerosols are also formed as the result of photochemical reactions involving gaseous contaminants in the atmosphere. Liquid aerosols include the sulfuric acid mist formed by oxidation of sulfur dioxide from combustion processes and ether-soluble material which has not yet been chemically identified. The ether-soluble portion is believed composed mostly of matter which is formed by atmospheric chemical reactions of organic material.

A considerable fraction of the solid particulate matter found in the atmosphere is emitted from many types of industrial operations such as mineral crushing, metal surface preparation, metal melting operations, and soot, ash, and dust from liquid fuel burning.

Table XIII gives estimates of aerosol emissions from industrial processes. It can be seen that tonnage-wise the amount of aerosols emitted from industrial operations is very small compared to the amounts of gaseous contaminants. To the total aerosol emissions shown, however, must be added an undetermined amount of dust created from road abrasion, naturally occurring dusts and pollens as well as aerosols caused by atmospheric reaction of certain gaseous contaminants.

Predictions of Future Problems

Knowledge of the rate of change in the quantity of air pollution expected due to a change in industrial, commercial, and domestic activity from year to year is important to a control program.

Table XV—Los Angeles County Alert Stages for Toxic Air Contaminants[a]

Air Contaminant	—Alert Stages, Parts per Million of Air— First Alert	Second Alert	Third Alert
Carbon monoxide	100	200	300
Nitrogen oxides	3	5	10
Sulfur oxides	3	5	10
Ozone	0.5	1.0	1.5

[a] These alert stages are established by Rule 156 in Regulation VII, Emergencies, of the Los Angeles County Air Pollution Control District. The Regulation was designed to prevent excessive buildup of air contaminants and to avoid any possibility of a catastrophe caused by toxic concentrations of air contaminants. The Regulation provides for continuously maintained sampling stations, measuring the concentrations of air contaminants in accordance with procedures and recommendations of a Scientific Committee. Whenever the concentration of any of the above contaminants has been verified as reaching the first alert stage, the burning of combustible refuse in an open fire in the Los Angeles Basin is prohibited and request for car pool activation is transmitted. If higher alert stages are reached, an Emergency Action Committee and the Air Pollution Control Board of the County are activated for the purpose of advising on action to be taken during the emergency. This action may involve the curtailing of industrial operations as scheduled on shutdown plans submitted by industrial and manufacturing companies. Key companies are notified of alert stages and actions to be taken by a direct radio communication system

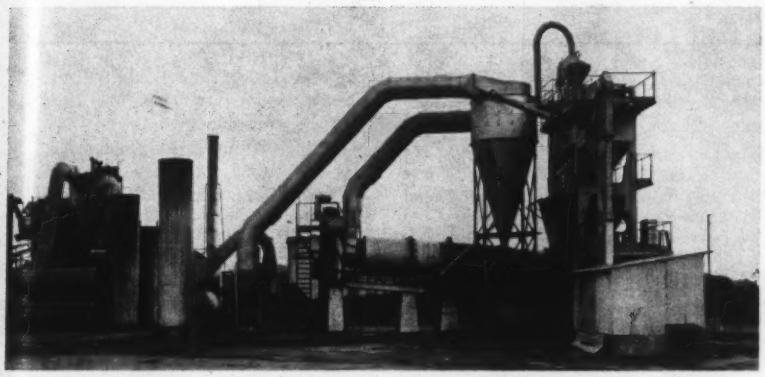

Fig. 11. Hot asphaltic concrete batching plant with cyclone and water scrubber control system.

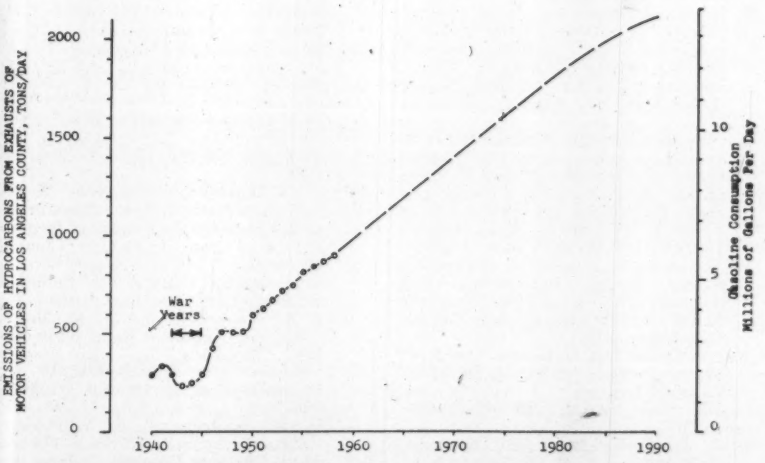

Fig. 12. Yearly variation of hydrocarbon emissions from motor vehicle exhaust based on present emission rates, past sales of gasoline, and estimated future consumption of gasoline.

In a community where there is little yearly change, a single survey may suffice to determine the present and future extent of the air pollution problem, except where new processes are substituted for old. However, most urban communities affected by air pollution are expanding and consequently find their problems are growing with industrial and population expansion. Surveys made at regular intervals serve as a basis for an evaluation of the control program as well as a basis for determining future policies.

The growth of an air pollution problem may not necessarily involve proportionately higher concentrations of contaminants, but may involve a greater geographical extension of air pollution, as suburbs and outlying industrial areas are extended.

Projected figures would also afford an estimate of the future effects of a particular control measure and an estimate of future emissions. As an example, Fig. 12 shows the estimated yearly increases in hydrocarbon emissions from automobiles in Los Angeles County. This Fig. may be used to estimate the long effects of any future automotive control program.

Limitations and Advantages of a Total Air Pollution Survey Program

It cannot be expected that a survey program alone will give accurate data as to actual concentrations of contaminants expected in a community. Where photochemically produced smog is a large factor, such as in Los Angeles, the contaminants emitted are not those which are the most troublesome per se. The critical phytotoxicants, eye irritating compounds, and ozone are all apparently produced from reactions in the atmosphere and are not emitted, to any important extent, directly from artificial processes. Much more study is necessary to determine the relationship between concentrations of contaminants as they are emitted and the atmospheric reaction products of these contaminants.

Climatic differences also do not allow accurate comparison of a problem from one community to another based on total air pollution data. Meteorological variations are at least as important as differences in emission rates in determining air pollution levels.

Total air pollution figures do not, in themselves, indicate which materials emitted are the most potent smog-forming reactants. If it is determined, for example, that a certain type of hydrocarbon is not a factor in an air pollution problem, or perhaps that another particular organic material is an especially important factor, survey programs can be oriented to obtain better data regarding emissions of specific chemical types. Until that time, however, and

Table XVI—Summary of Air Contaminant Emissions in Los Angeles County in Tons per Day

Source	Organic Gases				Inorganic Gases			
	Hydrocarbons	Aldehydes and Ketones	Other Organics	Aerosols	Nitrogen Oxides	Sulfur Dioxide	Carbon Monoxide	Other Inorganics
Transportation								
Automobiles[b]	740	9	12	24	250	20	6850	*n*
Trucks and buses (gasoline)	270	3	4	9	95	8	2000	*n*
Trucks and buses (diesel)	4	*n*	*n*	1	4	1	3	*n*
Petroleum								
Refining	50	2	*n*	5	5	50	700	4
Storage[c]	80	0	0	0	0	0	0	0
Marketing	55	0	0	0	0	0	0	0
Production	60	*n*	0	0	*u*	*n*	*u*	0
Organic solvent uses								
Surface coating	190	25	20	3	0	0	0	0
Degreasing	20	*n*	40	0	0	0	0	0
Dry cleaning	20	*n*	10	*n*	0	0	0	0
Other	70	20	20	*n*	0	0	0	0
Combustion of fuels								
Liquid	2	1	4	30	170	360	*n*	*n*
Gaseous	4	*n*	3	10	130	40	1	*n*
Incineration								
Industrial and commercial	*n*	*n*	1	*n*	*n*	*n*	1	*n*
Municipal	*n*	*n*	3	3	3	1	3	*n*
Other	*n*	0	*n*	1	*n*	*n*	*n*	*n*
Chemical								
Sulfur and sulfuric acid	0	0	0	0	0	45	0	0
Other	16	8	16	10	*n*	1	*n*	1
Metals	0	0	0	6	0	*n*	175	0
Minerals	2	0	0	4	0	*n*	*u*	0
Miscellaneous	*u*	0	*u*	2	0	*u*	0	*u*

[a] *u*, unknown, *n*, negligible, less than 0.5 ton per day.
[b] Includes trucks under 4000 pounds unladen weight.
[c] Includes storage of petroleum products at refining and marketing installations.

without any firm basis for excluding one contaminant from consideration as being less imporant than another, accurate emission data should be obtained on all materials which are not natural constituents of pure air.

For a large community, the cost of conducting a periodic total pollution survey is considerable, especially when stack sampling must be conducted. With a knowledge of all of the limitations, the responsible agency must make a decision as to the feasibility and desirability, or extent, of a total air pollution survey.

A total air pollution survey program has its principal value in pointing out the relative contribution of various types of sources toward an air pollution problem as a whole. From such data, a graphical distribution of sources can be made which may allow the formation of clean air zones such as provided in certain European cities. This can be done, however, only after meteorological conditions are also studied.

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A PRELIMINARY SURVEY of HYDROCARBON-DERIVED OXYGENATED MATERIAL in Automobile EXHAUST GASES*

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Complete combustion of fuels is seldom realized with internal combustion engines. Therefore, the exhaust products from these engines contain various species of hydrocarbon-derived oxygenated materials—hereafter referred to simply as "oxygenates." Several problems in connection with engine uses, and air pollution problems in particular, require information about these materials; this work by staff members of the Bureau of Mines, U. S. Department of the Interior, Bartlesville, Okla., was done to outline the types and quantities that might be found in automotive engine exhausts.

Methods using gas chromatography to analyze for many of these oxygenates have been described.[1-4] Other reports describe the use of chromatographic techniques to determine the individual oxygenates that occur in preflame mixtures.[5,6] Modifications of these methods were developed to adapt them to determine oxygenates found in automotive exhaust gas and to provide suitable separations of the oxygenates from unmodified hydrocarbons. Formaldehyde was not determined; it is presumed to be polymerized in the sample inlet system and on the column packing. In addition, it may be partially reduced to methanol. Because of these difficulties no suitable chromatographic method for its determination has been developed. Compounds that are determined by the methods described include ethylene and propylene oxides, methanol, ethanol, isopropanol, propanol, acetone, methyl ethyl ketone, acetaldehyde, and propionaldehyde.

The quantity of oxygenates produced by an engine varies with speed, load, and other engine factors. For some conditions, about 500 ml of the exhaust must be collected in order to obtain sufficient oxygenates for a chromatographic analysis by the techniques described. This amount of exhaust gas contains about 90 mg of water, and such a quantity of water is eluted from a gas chromatographic column in a broad band that may tend to obscure other oxygenate peaks. The removal of this water, an important step in the analysis of oxygenates, is difficult to accomplish by chemical means without seriously affecting the oxygenates. The problem was partially solved by removing the water by chromatographic methods, but this required compromising the sample to limit the total quantity of water and yet provide enough oxygenates for identification of all quantitatively significant components.

It was desirable to increase the ratio of oxygenates to interfering materials, such as water, in the exhaust gases. This was found to be possible by operating the engine under motored conditions, decelerating conditions, or when the engine was deliberately misfired. Most of the data obtained in this study were taken on exhaust gases produced during these operating conditions because they were favorable to experimental pro-

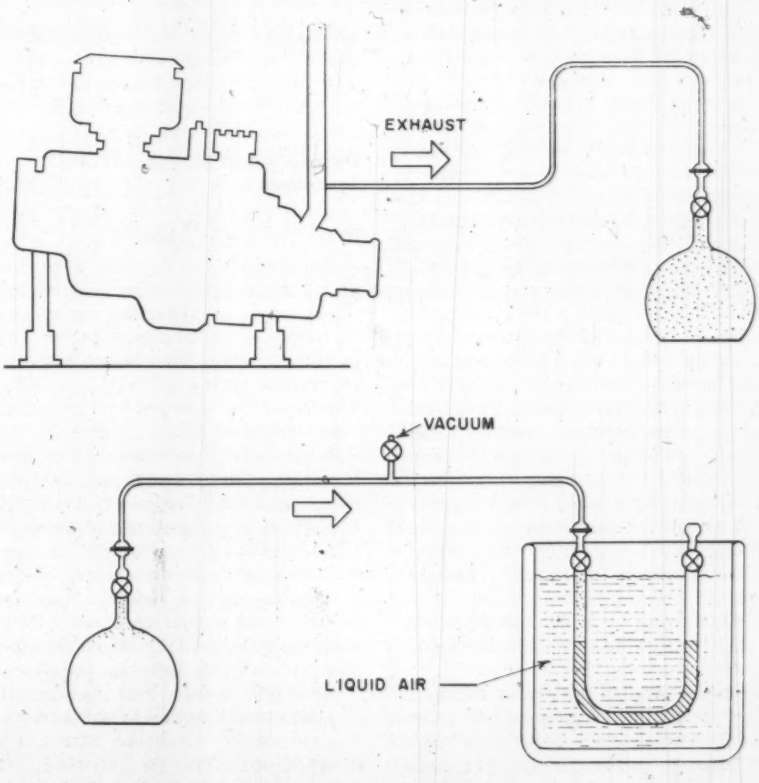

Fig. 1. Exhaust gas collection system.

* Presented at the 53rd Annual Meeting of APCA, May 22–26, 1960, Netherland-Hilton Hotel, Cincinnati, Ohio.

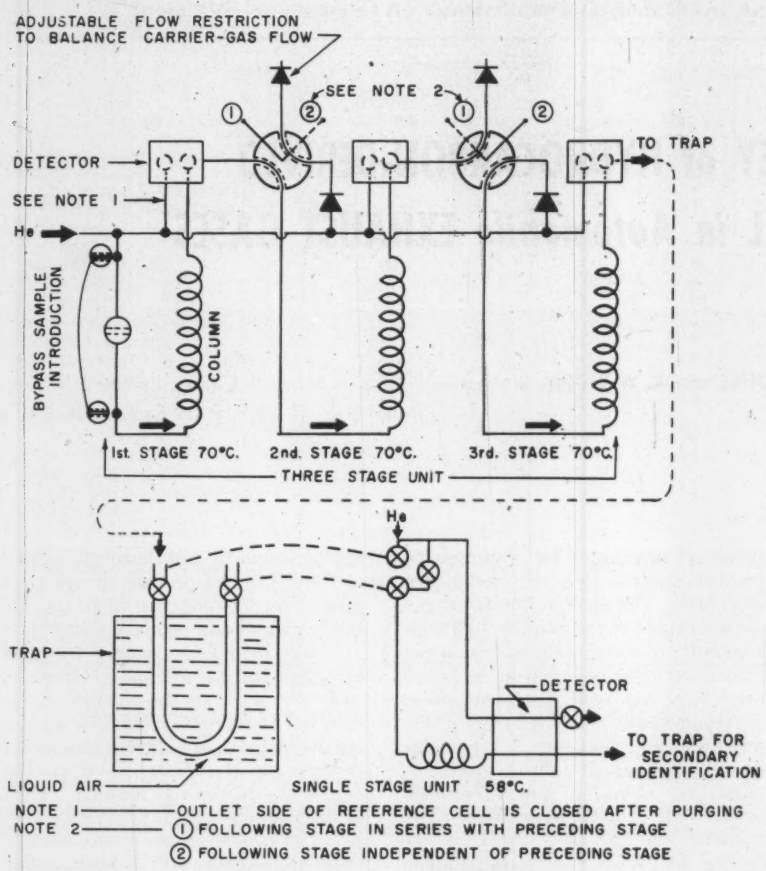

Fig. 2. Flow schematic of GLPC analytical system.

cedure and similar to conditions often encountered in automotive operation. However, late in the study the oxygenates in cruise exhausts were determined with an ionization-type detector that was highly sensitive to trace amounts of oxygenates and relatively insensitive to water.

The key problem in using gas chromatography for the analyses of exhaust gases is to shift the elution points of water and hydrocarbons so that they do not cover small oxygenate peaks. Chromatographic columns that employ a highly polar substrate, such as glycerol, retain water and oxygenates for a much longer time than hydrocarbons of a corresponding boiling range. Therefore, polar column packings were used in the first two stages of a three-stage gas chromatographic system to effect a major separation between hydrocarbons, oxygenates, and water. The third, an essentially nonpolar silicone column, served principally to aid in over-all separation of compounds.

The analytical technique for exhaust gases was designed to elute all hydrocarbons through *n*-heptane ahead of the low-boiling oxygenates, and to retain water until all major oxygenated components were passed. The technique also provided for reanalysis of portions of those compounds eluted from the three-stage unit with a single-stage chromatograph having higher resolving power than the staged unit.

Description of Equipment and Technique

Mode of Engine Operation

Exhaust gases for the study were produced in an automotive V-8 engine connected to an absorption dynamometer and to an auxiliary engine appropriately coupled to motor the test engine or to control its deceleration rate. The engine was equipped with a conventional automatic transmission.

Before any exhaust samples were taken, the engine was warmed up using either the test fuel or house-brand regular grade gasoline and with speed and load adjusted to simulate 40 mph level-road automotive operation. After a suitable warmup period, the carburetor bowl was drained and refilled with the test fuel, after which the system was ready for operation as follows.

Simulated cruise: This was meant to simulate the engine condition when the vehicle for which the engine was designed was driven on level road. It was established by loading the engine with a dynamometer at a drive-shaft speed corresponding to the simulated road speed, and with the load adjusted to the manufacturer's vehicle power-requirement data. Exhaust gas samples were taken during stabilized operation.

Misfired: Same as simulated cruise, except one spark plug wire was removed.

Deceleration: Starting from stable simulated cruise at 50 mph, the throttle was closed, dynamometer load simultaneously was reduced to zero, and the auxiliary power was applied through the dynamometer coupling to limit deceleration rate. Deceleration was controlled to drop the indicated speed from 50 to 20 mph in 25 sec., and the exhaust gas sample was taken as indicated speed dropped past 40 mph. The sampling time was not allowed to exceed five sec.

Motored: Starting from stable simulated cruise at 40 mph, the ignition was turned off, the throttle position was left unchanged, the dynamometer load was reduced to zero, and the indicated speed was maintained at 40 mph with an auxiliary engine. Exhaust gas samples were taken as soon as a stable condition was reached.

Exhaust Gas Sampling and Transfer

Figure 1 illustrates the sampling and transfer system. The sample was taken from the exhaust stream into a 500-ml. evacuated flask. After being filled with exhaust gases, the flask was immersed in liquid air, and the gases not condensed at liquid air temperatures were pumped off. The remaining compounds were subsequently vapor transferred to a 10-ml stainless steel "U" tube used as a sample cell for a gas chromatograph. When this transfer was properly accomplished, the sample cell contained carbon dioxide (CO_2), hydrocarbons (excluding methane), hydrocarbon oxygenates, and water. At this condition the sample was ready to introduce into the chromatographic analyzer.

Gas Liquid Partition Chromatographic (GLPC) Analytical System

A three-stage gas chromatograph was chosen to handle the various oxygenates likely to be found. Additional resolution, as required, was accomplished by collecting fractions from the three-stage unit and reanalyzing this fraction in a single-stage unit.

The GLPC analytical systems are shown in Fig. 2. The three-stage system, which has been described,[9] used the following chromatographic columns:

First stage—four feet of partition column using a glycerol substrate and six feet of partition columns using polyethylene glycol 400 substrate.

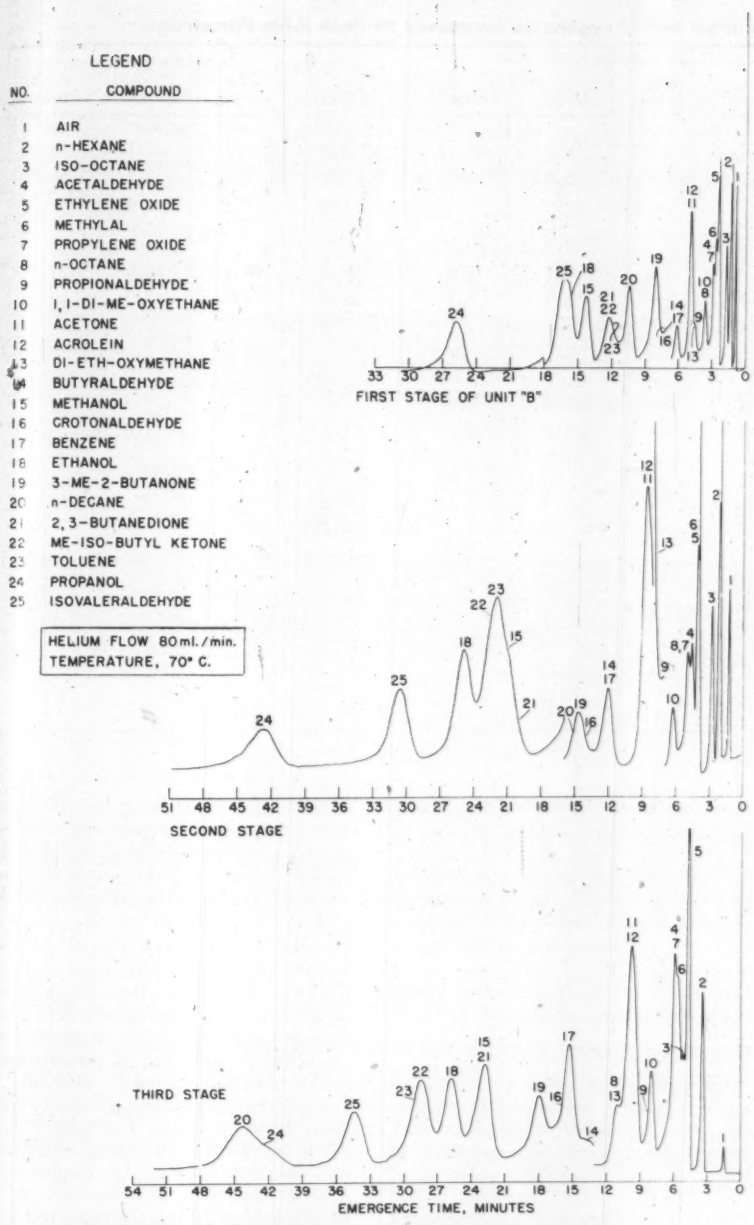

Fig. 3. Separation characteristics of three-stage chromatographic unit.

Second stage—five feet of partition column, polyethylene glycol 400 substrate.

Third stage—five feet of partition column, Dow-Corning 550 silicone oil substrate.

The single-stage unit was fitted with a 20-ft column prepared with a commercial plasticizer, Reoplex 400.

The detectors shown in Fig. 2 are thermal conductivity cells using thermistor elements. The general design has been covered in other reports.[7,9]

An outstanding feature of this multistaged GLPC system is that any peak may be identified on four different chromatograms. In complex samples such as may be recovered from exhaust gases, this is a substantial aid in identifying unknown compounds.

Figure 3 illustrates separation characteristics of the three-stage unit, and Fig. 4 is a chromatogram of the same sample made with the single-stage analyzer. In most instances peak resolution is improved as the sample progresses through the three stages, but sometimes peak shifting will cause pairs of compounds to overlap. The class separation between hydrocarbons and oxygenates is good for hydrocarbons boiling below *n*-octane, but hydrocarbons with boiling points near that of *n*-decane can seriously interfere with the oxygenate peaks. Resolution is improved in the single-stage analyzer, but the compounds that can be handled are limited to materials of lower boiling range than those that can be satisfactorily handled in the three-stage unit. For example, using a column temperature of 58°C, compounds admitted to the single-stage unit should have emergence times not appreciably greater than that of *n*-propanol, but the three-stage unit could be used for *n*-pentanol.

Experimental Data

The two fuels employed for these studies were ASTM grade iso-octane and a technical grade *n*-hexane of 95+ mol percent purity. The *n*-hexane was percolated through silica gel to remove traces of aromatics.

Exhaust gases produced during simulated cruise: Figure 5 shows single-staged chromatograms of exhaust gases sampled under cruise conditions. An ionization-type detector using argon for carrier gas was used for these determinations because the concentration of oxygenates was too low for satisfactory detection by thermal conductivity methods. Acetone, isobutyraldehyde, and acrolein were most prominent in these samples, but acetaldehyde and crotonaldehyde also were major components.

Exhaust gases from a misfired engine: Figure 6 shows single-stage chromatograms of exhaust gases from an engine caused to misfire on one cylinder. Acetaldehyde, acetone, and isobutyraldehyde are common to the exhausts from the two fuels, *n*-hexane and iso-octane; acrolein, commonly a major constituent of the oxygenate class in exhaust gas, was not detected. The other compounds that were identified in these exhausts are commonly produced by many fuels during other conditions of engine operation.

Exhaust gases from a decelerating engine: Figure 7 gives single-stage chromatograms of exhausts from a decelerating engine. The total of oxygenates is significantly larger than that produced during either cruise or misfired operation. Qualitatively, these exhausts are generally similar to those from a misfired engine, but contain acrolein as a relatively large component that is usually present in exhausts from firing engines.

Figure 7 illustrates the complexity of exhaust gas composition; because of this complexity, chromatograms from two or more columns (of different type) are almost essential to satisfactory identification of any of the components. Even with the most favorable separations, it is highly possible that elutions indicated by single peaks may contain several compounds.

Table I—Composition of Exhaust Gas Oxygenates Expressed as Peak Area Percentage

	n-Hexane				Isooctane			
	Cruise	Mis-firing	Decel.	Motored	Cruise	Mis-firing	Decel.	Motored
Ethyl ether	—	—	—	8.7	—	—	—	—
Acetaldehyde and ethylene oxide[a]	13.7	6.3	6.0	51.6	4.6	1.9	7.1	—
Propylene oxide[a] / Methylal	—	—	3.5	1.6	1.4	2.6	3.2	26.9
Furan[a]	—	—	—	—	—	2.4	1.3	—
Ethyl-*n*-butyl ether	—	—	—	—	—	2.4	—	—
Proponaldehyde[a]	7.2	10.3	3.8	10.5	—	—	1.6	—
Acetone[a] / Isobutyraldehyde[a]	13.9	2.9	2.7	2.0	25.2	38.4	15.0	27.8
Acrolein[a]	15.4	—	5.0	5.1	10.9	—	12.2	—
Di-et-oxymethane	—	10.3	—	—	—	—	—	—
Me-acrolein / Tetrahydrofuran[a] / 2-Me-tetrahydrofuran[a]	—	—	—	—	—	8.2	—	2.9
Methanol[a] / *n*-Butyraldehyde[a]	16 3	18.4	18.2	7.6	—	—	8.8	—
Me-et ketone[a]	—	—	6.8	2.0	—	—	1.9	—
2,5-Di-hydrofuran / 1,2-Di-et-oxyethane	—	—	12.6	—	—	18.2	—	37.6
Isopropanol / Ethanol[a]	—	14.7	9.7	—	12.9	—	—	—
Crotonaldehyde	21.6	—	—	—	13.6	24.0	—	—
3-Me-2-butanone[a]	—	—	—	3.4	—	—	—	—
3-Buten-2-one[a]	—	—	4.0	1.9	—	—	—	—
2,4-Di-me-3-Pentanone / *a*-Ethyl butyraldehyde	—	—	1.4	—	—	—	—	—
1,1,1-Tri-me-acetone	—	18.7	15.2	—	—	—	—	—
3-Pentanone	—	—	—	—	—	—	—	2.6
sec-Butanol[a]	—	—	—	—	—	—	4.3	—
n-Propanol[a]	—	—	2.2	—	—	—	—	—
Isovaleraldehyde[a]	—	—	2.2	—	—	—	—	—
Unknowns (total)	11.8	18.4	6.7	5.6	31.4	1.9	44.6	2.0

[a] Positively identified and verified by GLPC.

Exhaust gases from a motored engine: Figure 8 shows three-stage chromatograms of an exhaust gas from a motored engine. A fraction from the third stage was recovered for reanalysis in the single-stage unit and the material included in this fraction was indicated on the third-stage chromatogram. The chromatogram from this reanalysis is shown in Fig. 9.

Compounds determined by analysis in the three-stage chromatogram are not considered positively identified until verified by several reanalyses in the single-stage unit. In Fig. 9, the 1,2-dimethoxyethane, isopropanol, ethanol, and 3-pentanone are not identified, although the fraction presumably contained these materials. This may be due in part to the large benzene and 3-methyl-2-butanone peaks having obscured peaks which represent ethanol, isopropanol, and 1,2-dimethoxyethane; 3-pentanone is not evident in Fig. 9. This indicates that the peaks labeled 3-pentanone in Fig. 8 may be improperly identified. The compounds 4-methyl-2-pentanone, *n*-propanol, and isovaleraldehyde were on the original chromatogram but were deleted from Fig. 9 because the chromatogram was excessively large for reproduction.

Quantitative Results

Quantitative data from the chromatograms obtained in the work reported are estimates only; errors may arise because of incomplete separation of materials and instability of some of the oxygenates. For example, in the presence of water the aldehydes are susceptible to partial reduction to the corresponding alcohol. Nevertheless, useful estimates of the oxygenates in exhaust gases may be made. Typical data from a single-stage chromatograph are shown in Table I. Aldehydes, epoxides, ketones, and alcohols are the principal class constituents within which acetaldehydes and ethylene oxide are predominant. These materials are not readily separated, but later GLPC analyses have shown that the mixture is at least 90% acetaldehyde under conditions studied. For convenience, quantitative data for all unidentified peaks were grouped under "unknown."

Data on oxygenates produced under four different engine conditions, and using two fuels during each condition, are shown in Table II. Engine operating condition has a marked effect on total oxygenates; the exhaust from a motored engine is relatively rich in oxygenates, while the exhaust from an engine simulating cruise is virtually free of these materials.

Table II—Comparison of Total Oxygenates Produced Under Various Engine Operating Conditions

Expressed as parts of oxygenated material per million parts of exhaust gas—weight basis

Engine Operating Condition	Est. Ppm in Exhaust Gases
Fuel: *n*-Hexane	
40 mph cruise	65.1
40 mph cruise with one spark plug wire removed	1,712.
Deceleration	3,800.
Motored	54,200.
Fuel: Isooctane	
40 mph cruise	45.
40 mph cruise with one spark plug wire removed	132.7
Deceleration	984.
Motored	17,750

Limitations of Analytical Techniques

Formaldehyde is accepted as one of the more abundant oxygenates found in exhaust gases, but it is difficult to resolve it chromatographically as a monomer since formaldehyde gas polymerizes rapidly at temperatures below 100°C. There is some evidence that it can be separated as a low molecular weight polymer, but the conditions and techniques for the separation are not well defined.

Some efforts were made to reduce formaldehyde to methanol, and chromatographically analyze for the alcohol.

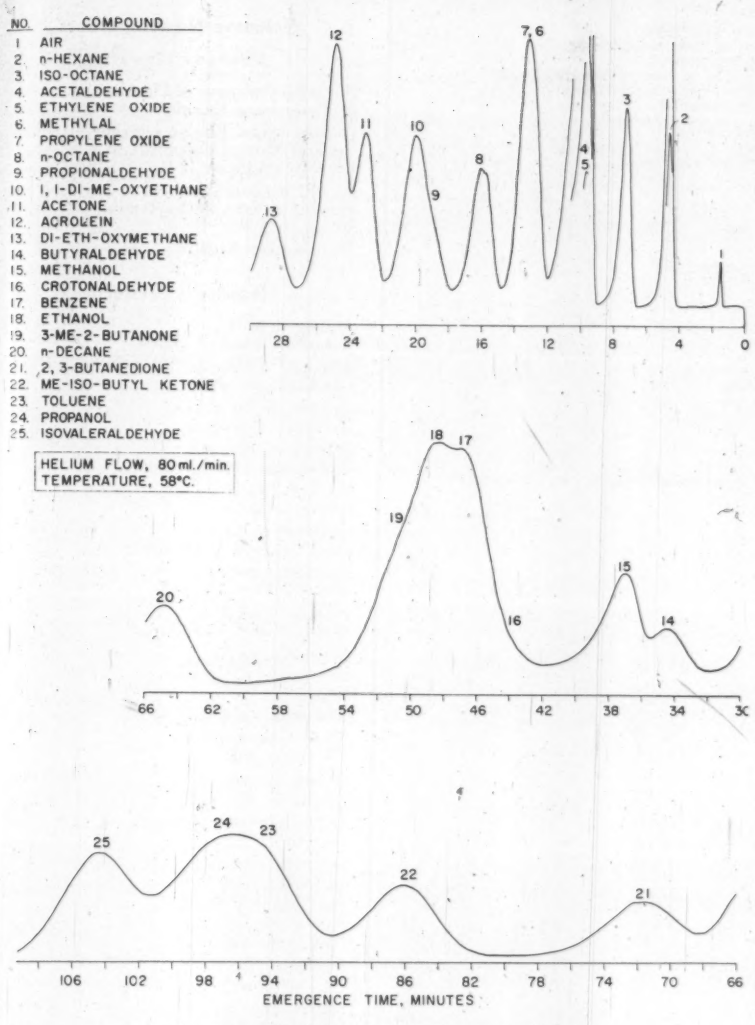

Fig. 4. Separation characteristics of chromatographic unit.

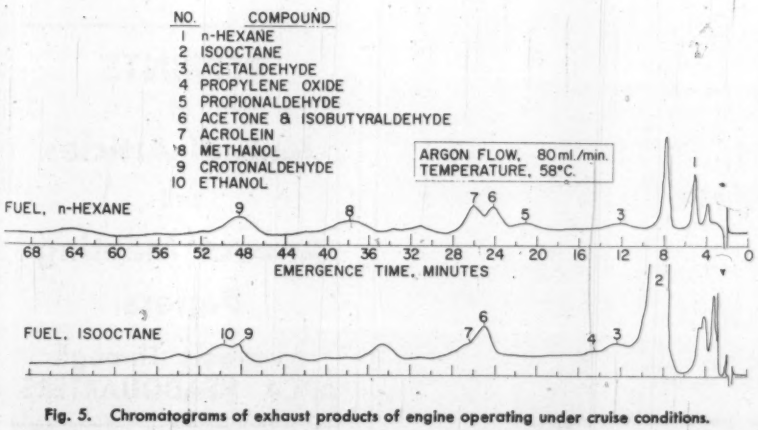

Fig. 5. Chromatograms of exhaust products of engine operating under cruise conditions.

However, the degree of conversion was not adequate and the reducing agent appeared to affect other oxygenates in the exhaust sample. Thus, the technique used for this work did not provide for the determination of formaldehyde.

Fatty acids, especially those of lower molecular weight, react with the hydroxyl (OH) groups of the polyglycol substrates used for column packings. Therefore, the method of analysis was not applicable to the fatty acids. Analyses for these acids were not attempted in the work reported because it was not expected that they were an important constituent of the exhausts. However, these are tentative assumptions and may be in error.

Closure

Both mode of engine operation and chemical composition of the fuel influence the emissions of exhaust gases. Influence is both qualitative and quantitative.

More than 30 oxygenates in the molecular weight range of ethylene oxide through pentanol have been found in automobile exhaust gases: 14 have been identified positively, and tentative identifications have been established for another 18.

Low concentrations of oxygenates are present in exhausts produced during automotive engine cruise and acceleration operations when ignition is consistently good. However, ignition malfunctions will significantly raise emissions of oxygenates; and, during periods of deceleration or motored operation, the amount of oxygenates may approach the quantity of hydrocarbons in the exhaust gases.

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(*See p. 372 for Figs. 6 and 8, and p. 373 for Fig. 9.*)

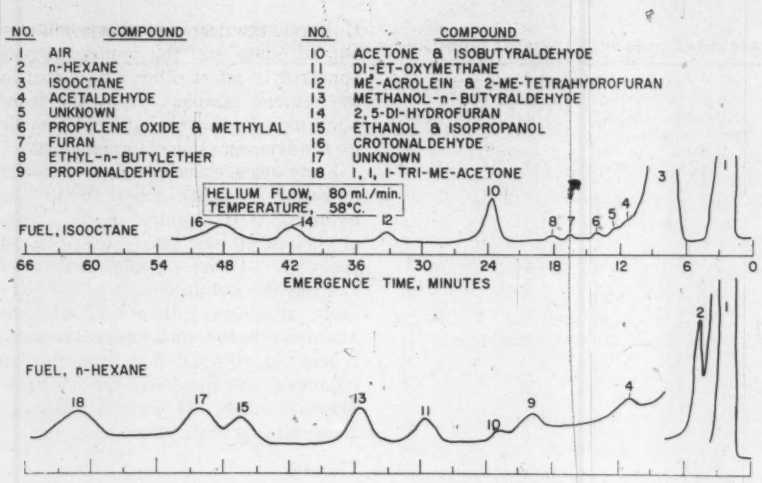

Fig. 6. Chromatogram of exhaust products of engine with one plug wire removed.

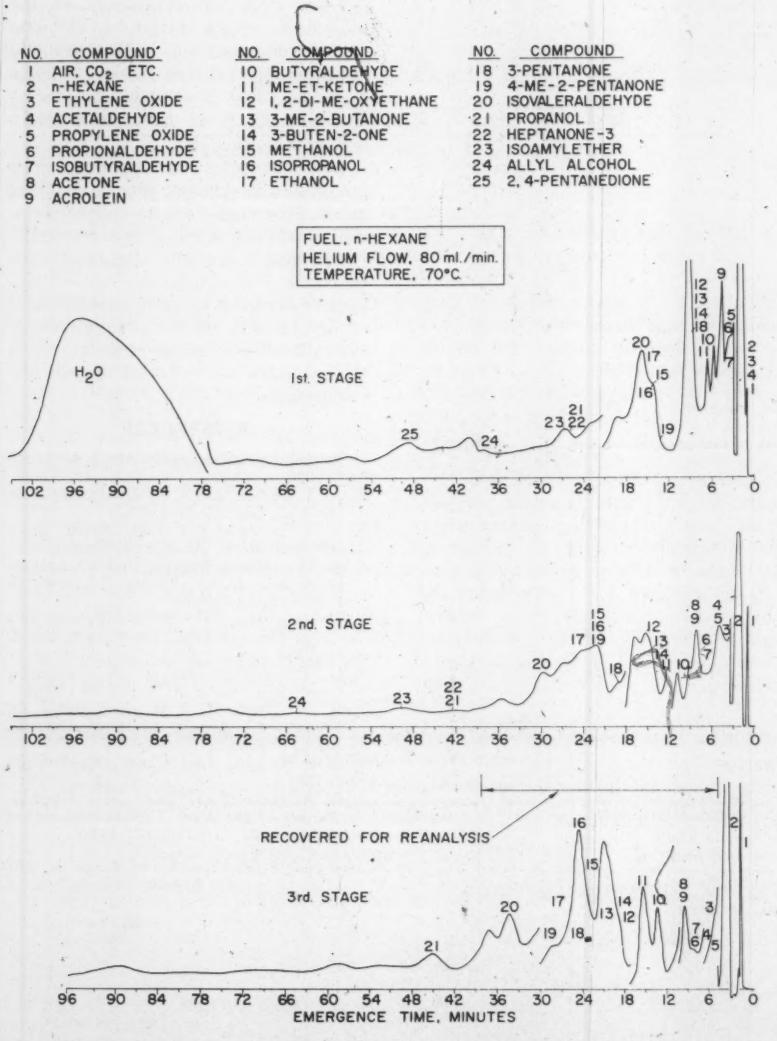

Fig. 8. Chromatograms of exhaust products of a motored engine.

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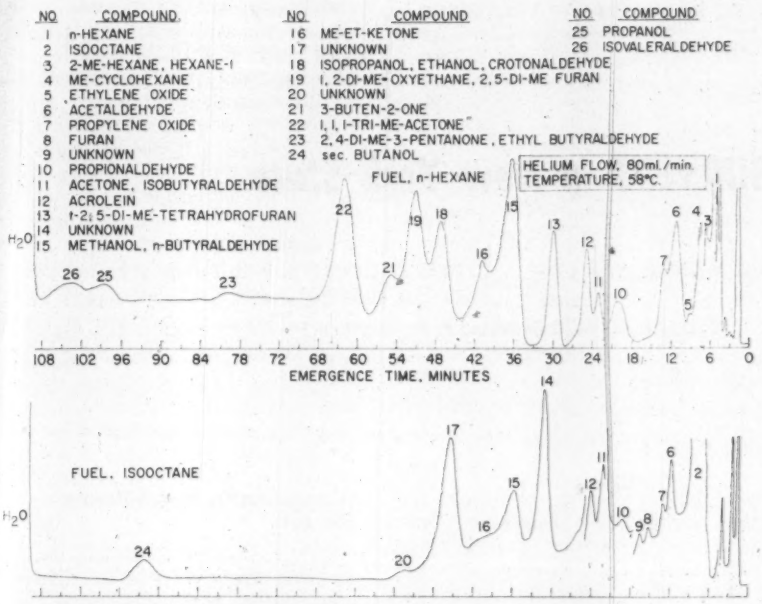

Fig. 7. Chromatograms of exhaust products from decelerating engine.

NO.	COMPOUND	NO.	COMPOUND
1.	AIR	10.	ACROLEIN
2.	n-HEXANE	11.	t-2,5-DI-ME-TETRAHYDROFURAN
3.	METHYLCYCLOPENTANE	12.	BUTYRALDEHYDE
4.	ETHYL ETHER	13	METHANOL, C-2, 5-DI-ME-TETRAHYDROFURAN
5.	ETHYLENE OXIDE	14.	METHYL ETHYL KETONE
6.	ACETALDEHYDE	15.	BENZENE
7.	PROPYLENE OXIDE	16.	3-METHYL-2-BUTANONE
8.	PROPIONALDEHYDE	17.	3-BUTEN-2-ONE
9.	ACETONE	18.	UNKNOWN

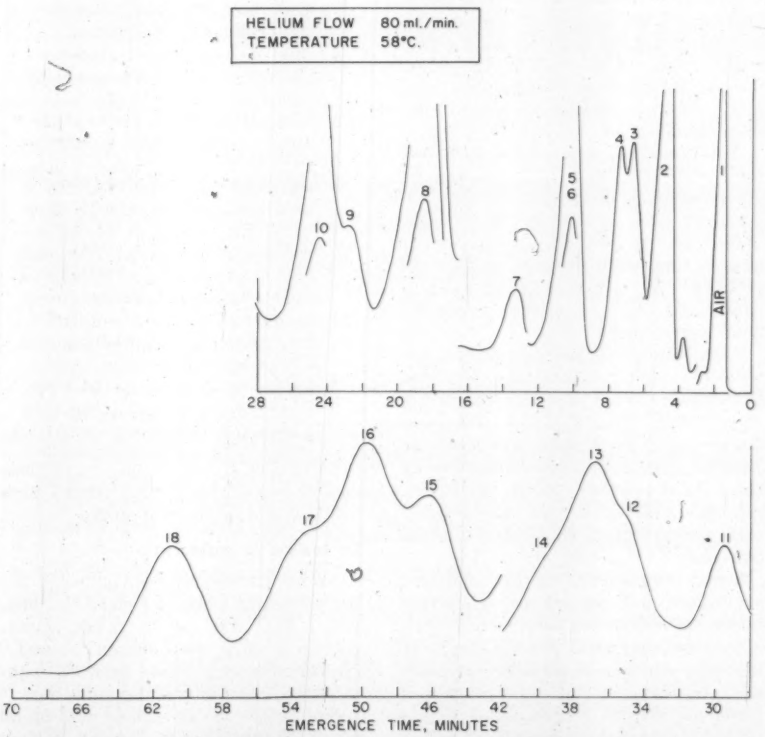

Fig. 9. Reanalysis of fraction recovered from three-stage unit.

SCIENTISTS, PHYSICIAN, NEWSPAPERMAN MERITED 1959 CLEAN AIR AWARDS

Three scientists, a physician, and a retired newspaperman have won the 1959 annual Clean Air Awards for outstanding achievement in air pollution abatement announced William H. T. Holden, Chairman of the Clean Air Awards Committee.

Those named are Dr. Alexander Goetz, California Institute of Technology, Pasadena; Dr. John T. Middleton, University of California at Riverside; Dr. Steven Nicksic, California Research Corporation; and Magner White, retired news reporter.

They were honored at a Los Angeles Chamber of Commerce luncheon where they were presented awards in the form of plaques.

The annual presentation was inaugurated three years ago, by the Los Angeles County Board of Supervisors to stimulate voluntary efforts by individuals and industry to help control smog. Selection of winners is made by an independent committee.

Dr. Alexander Goetz was recognized for developing instruments to detect air pollutants. His method was labeled "of major importance in the control of air pollution in the Los Angeles Basin."

Pioneering Rewarded

Dr. John T. Middleton was named for pioneering in establishing the connection between air pollution and plant damage. Dr. Middleton was the first to publish a comprehensive description of the effect of air pollution on vegetation in the Los Angeles area.

Dr. Hurley Motley was selected for work in determining the effect of smog on breathing.

Dr. Steven Nicksic was honored for development of an analyzing instrument, which gives rapid measure of olefins in exhaust gases and reaction chamber materials.

Magner White was recognized for diligent research and outstanding reporting over a period of years on the smog problem in Los Angeles County.

Harold Wright, Manager of the Los Angeles Chamber of Commerce, will host the luncheon and Air Pollution Control Officer Smith Griswold will introduce the award winners.

The awards committee includes: Dr. Madeleine Fallon, Los Angeles County Medical Association; Harry Faull, Pomona City Councilman; Neal A. Richardson, UCLA School of Engineering; Ed Stout, representing civic clubs; Jerry Kraus, Pasadena Realty Board; Dr. Frank Lockheart, USC School of Engineering; and Dr. Jack McKee, California Institute of Technology.

Comprehensive AREA SURVEYS in New York State*

CHARLES S. MANERI, P. E. Chief, Air Pollution Control Section, Bureau of Environmental Sanitation, New York State Department of Health, Albany, N. Y.
WILLIAM H. MEGONNELL, P. E., Regional Air Pollution Consultant, Region II, U. S. Public Health Service, New York, N. Y.

From 1954 through 1956, three statewide surveys were conducted to assess the extent and seriousness of air pollution in New York State. The surveys were made independently by separate agencies using different techniques, but their independent and composite conclusion was: air pollution is a widespread complaint in New York State communities of all sizes, and its abatement and control receive too little attention.

Largely based on this finding, the New York State Air Pollution Control Act[1] was passed in 1957. The Air Pollution Control Board, created within the Department of Health, was given broad powers and duties to achieve and maintain reasonable air cleanliness throughout the state. Rule-making and enforcement authority were deferred by law until July 1, 1959, but investigations to determine types, extent and seriousness of air contamination were authorized effective July 1, 1957.

Area Survey Plan Adopted

In their review of existing knowledge,[2] the board noted that few communities, despite recognition of local contamination, had undertaken objective studies to assess the nature and extent of their problems. Subjectively, certain sources and contaminants were obvious, but virtually no effort had been made to identify all contributors and their emissions.

The Air Pollution Control Act recognizes air as a natural resource and acknowledges its reasonable use according to rules and regulations which are scientifically based on cause and effect. Under the law, the board must "give due recognition to the fact that the quantity or characteristics of air contaminants or the duration of their presence in the atmosphere, which may cause air pollution in one area of the state, may cause less air pollution or not cause any air pollution in another area of the state . . ."

This provision precludes the adoption of arbitrary statewide air quality standards. Comprehensive, detailed surveys are necessary prerequisites to the adoption of local or regional rules and regulations.

Correction Facilitated

When the cause, behavior and effect of an area's air pollution are well-defined, correction—although never simple—is facilitated. St. Louis and Pittsburgh, for example, solved a major portion of their problem by controlling the use of a single type of fuel. Other communities, which failed to define their problem, discovered that extensive and costly measures did little to alleviate conditions.

The board adopted a plan to determine sources, vectors and receptors of air pollution in all areas of the state by comprehensive area surveys.[3] Individual and collective consideration of such factors will help evaluate the total problem and enable establishment of control activities, if needed, on intelligent, sound bases.

Enormity of the undertaking is obvious when one considers that, scattered throughout New York State's 50,000 square miles, there are about 1000 cities, towns and villages with population of 1000 or more. Previous surveys show that about one-half of the 447 communities reported in the three statewide surveys have air pollution problems they want corrected.

Gross assessment of the relative prevalence and importance of air pollution in various sections was needed. Therefore, the board divided the state into nine study areas for administration and coordination of survey work.[2] Based on knowledge of existing or potential problems, a priority schedule was adopted for future activity.

Information Gathered During Surveys

Staff and budget limitations necessitate that area surveys be based largely on available, readily obtainable information; at the same time, since important decisions will be based on the findings, surveys must be as complete and accurate as possible.

Each survey includes the following aspects:

1. A historical review of population, industry, agriculture, and transportation trends in the area.
2. An emission inventory in which contaminants are classified by type, amount, source category, and community of origin.
3. Analysis of meteorological data.
4. Consideration of topographical features.
5. Computation of probable atmospheric contaminant concentrations under various meteorological conditions and comparison of calculated values with sampling data, if any are available.
6. Review of complaint files and field observations and interviews to determine air pollution effects.
7. Assessing the existence and effectiveness of local ordinances and enforcement programs.
8. Preparing conclusions and recommendations based on the gathered information.

Ultimately, rules and regulations needed for the particular survey area will be based on these findings.

Emission Inventories

An air contaminant is defined in the Air Pollution Control Act as "a dust, fume, gas, mist, odor, smoke, vapor, pollen or any combination thereof." No distinction is made between man-made and natural contaminants.

Source inventories include data on all known contaminants, except carbon monoxide, carbon dioxide, and water

* Presented at the 53rd Annual Meeting of APCA, Netherland-Hilton Hotel, May 22–26, 1960, Cincinnati, Ohio.

vapor, created by human activity. Although these three substances are the most common products resulting from fuel combustion, they were not considered important as community air contaminants in source inventories. Sometimes carbon dioxide and water vapor can become troublesome, but both are present in "natural" air and are essential for plant and animal life. Carbon monoxide, which ultimately is converted to carbon dioxide in the atmosphere, is a deadly gas under certain conditions; therefore, its importance in congested city traffic should not be minimized.

Dust from eroded land, gases from landfill operations and swamps, and other materials whose relation to human activities is indirect, also are excluded as inventory data because of extreme difficulty in evaluating them quantitatively.

Of those contaminants which occur naturally, only ragweed pollen is considered in surveys, and this is usually limited to estimating ragweed-producing acreage and gathering available sampling data.

While smoke and odors are the most obvious of all air pollutants, they are not determined quantitatively. For completeness, however, the number and subjective descriptions of observed smoke and odor sources, if available, are included in inventories.

Contaminants are classified as aerosols and gases, with gases being grouped into the compounds of sulfur, nitrogen, the halogens, and organics.

In the original program plan, air contaminant source groups were categorized as follows.

1 Industrial: establishments in which the primary activity is processing, refining, smelting or manufacturing of materials or products, rather than sales or services.

2 Commercial: hotels, laundries, theaters, bakeries, garages, service stations, stores, and other privately owned business and mercantile firms that engage mainly in sales and services.

3 Public: local, state, and federal government installations such as public housing, governmental office buildings, post offices, maintenance garages for public vehicles, municipal incinerators and dumps, schools, hospitals and similar institutions, utilities and municipal transport facilities.

4 Private: domestic heating plants, apartment-house and backyard incinerators, trash and leaf burning and automobile exhausts.

A pilot study demonstrated the difficulty of subdividing data into these four categories, and the program plan later was revised to include only two broad source categories.

1 Industrial: factories and industrial plants, as defined by the New York State Labor Law,[4] and electric power generating plants (which are excluded from that law).

2 Nonindustrial, which includes all other sources.

Field Methodology

The Air Pollution Act specifies that "technical, scientific, legal or other services shall be performed, insofar as practicable, by personnel of the departments of health, agriculture and markets, commerce, conservation, labor and other departments or agencies of the state, without additional compensation." When personnel not available within state agencies are required, employment of additional personnel, including consultants, is authorized. The executive secretary of the board arranges integration into the program of personnel who are engaged in this activity.

Primarily, field work is the responsibility of the State Health and Labor departments, but the Commerce, Conservation and Agriculture and Markets departments provide services such as compiling pertinent statistical data on automobile registrations, motor vehicle fuel consumption, population, employment, forest and farm acreage, herbicide and insecticide use, and similar tabulations.

For convenience, sources are divided into two main classes: specific and multiple.

Specific sources are surveyed individually and include industrial plants, municipal refuse-disposal facilities, utilities, urban transport agencies and larger commercial establishments.

Multiple sources are so numerous that for practical purposes data are obtained from gross statistics on such places as residences, private incinerators motor vehicles, and many others. Their individual small emissions in aggregate contribute significantly to community air contamination.

About one month before field work is undertaken, emission inventory forms are mailed with covering letters to industrial plants in the survey area. Since registration of all factories and mercantile establishments is required by the Labor Law, the use of Department of Labor listings virtually assures complete coverage of all industrial establishments. Objectives of the survey are explained in the letter, and management is asked to supply air contaminant emission data or information on which emission estimates can be based.

When the returned replies are complete and data appear to check with information available to official agencies, plant visits are not carried out. If returned forms are incomplete or appear to be inaccurate, or if questionnaires are not returned, survey team personnel visit the plants to obtain the desired data.

In addition to process effluents, other industrial activities which emit contaminants, such as scrap burning, salvage operations, and heat and power producing facilities, are included in each plant survey.

Source sampling, however desirable, is precluded for the present by limited resources. Conferences with management, plant tours, materials balances, production records and test results, supplemented by team personnel experience and knowledge, are helpful in estimating emissions. When information is not otherwise available, estimates are based on published technical data; hundreds of papers were reviewed and emissions associated with a wide variety of industrial processes have been tabulated.[3]

Data from large nonindustrial sources are obtained through field visits and individual interviews with appropriate officials. Fuel dealers, solvent suppliers, and bulk fuel distributors supply information on their sales; purchasing records of schools, hospitals, and similar institutions are checked for types and amounts of fuel consumed, and institutional officials provide knowledge on their refuse-disposal practices. Dumps and incinerators are visited, and the composition and amounts of refuse burned are obtained from inspections, weigh records, truck counts and average capacities, and interviews with supervisors; information on backyard incineration, leaf burning, and similar air-polluting practices are obtained from municipal officials.

Estimating Emissions

Although obtaining reasonably accurate field data on fuel consumption, incineration of wastes and processing of materials can become quite complex, it is a relatively simple procedure in comparison to determining air contamination resulting from such activities.

Obviously, it would be impossible for the board to undertake the extensive research required to determine contaminant types and amounts emitted from the wide variety of sources encountered in a survey. Therefore, emission estimates must be based on published findings of various investigators who conducted studies on similar installations.

Except for industrial process emissions, almost complete reliance is placed on data reported by the Los Angeles

County Air Pollution Control District, Stanford Research Institute, Western Oil and Gas Association, and others in the California area. Considerable judgment must be and is used in employing these data when estimating types and quantities of contaminant resulting from individual processes. Certain published values are used directly; adjustments are made in others, particularly when combustion materials encountered in a survey vary markedly from those burned in research studies. At times, reliable estimates may be obtained by considering the composition of fuels and theoretical combustion reactions. Hydrocarbon-evaporation values are reduced, in accordance with relative vapor pressures, to take into consideration the existing temperature differences between New York and California. In estimating the amount of emissions to the atmosphere, effectiveness of any installed control device is considered.

Estimates thus obtained in this manner are believed reliable, but there is a pressing need for a more complete compendium of knowledge on emissions from various processes and activities.

Meteorology

A meteorological station is used in an area survey only when there are no available weather records for the vicinity. Usually, existing meteorological data and topographical information are sufficient to determine important influences on the local air pollution complex. One source of meteorological information is the National Records Center of the U. S. Weather Bureau at Asheville, N. C. This records repository, in many instances, can provide the basic meteorological data which are needed.

Though recognized as being subjective, field observations of plume travel and dispersion, wind flow, fogs, visibility, and inversions are an invaluable supplement to tabulated meteorological data. These field observations can be used as guides in intelligently interpreting data that have been obtained in other ways, such as from recording instruments and samplers.

Estimating Atmospheric Contaminant Concentrations

Concentrations of atmospheric contaminants under various wind speeds and inversion heights are readily computed from the survey area size and seasonal emission data, providing assumptions are made of inversion duration, wind speed and direction, homogeneity of contaminant mixing in the atmosphere, and topographic features of the area. This mathematical approach can produce the best and most reasonable estimates in the absence of sampling data. If sampling is conducted in the area, the reliability of calculated values may be checked.

The factors of importance can be combined and reduced to the following convenient formula:

$$C = \frac{0.8\ Qt}{WH\ (L + St)}$$

where

- C = the expected concentration in mg/m^3
- Q = pollutant emission rate in lbs/month
- t = time of inversion persistence in hrs
- W = width of area, perpendicular to wind direction, in mi
- L = length of area, parallel to wind direction, in mi
- H = height inversion in ft
- S = wind speed in mph

Effects

Complaint files, interviews with residents, and direct observations of the field staff disclose the effects of air contaminants in the survey area. Past studies are considered also. Weather and airline records are reviewed to detect frequency and duration of visibility reduction attributable to air pollution. Local allergists are contacted regarding pollinosis prevalence in the area. Health departments and hospitals often can provide information on other known or suspected health effects. County agricultural agents are interviewed to obtain data on plant and animal damage they believe is related to air pollution.

Experiences With the Method

The first survey undertaken under this plan was a pilot project in the Greater Elmira area. Field work was completed in five weeks in August and September of 1958 and a report has been prepared on this survey.[5]

The survey area, consisting of about 1/3 of Chemung county, contained one city, five towns, three incorporated villages (one of which straddled two town lines), and a large unincorporated suburban and rural area. It was determined from previous knowledge and by a preliminary field review that the selected survey area was likely to constitute a single air-pollution complex.

Although Greater Elmira's air pollution is not so pressing or complex as that in other areas of the state, its selection was based on two main factors:

1. Several requests from local officials in the area for assistance in controlling air pollution problems.
2. Suitability of this moderate-size geographical district for testing survey procedures in a pilot project. The area had a limited but diversified economy and included a multiplicity of jurisdictions.

Desirable changes could then be made in operational methods before proceeding to more populous and highly complex areas of the state.

Summary data resulting from the survey are given in Table I.

Sources emitted some 5000 tons of air contaminants monthly during the heating season; annually, some 40,000 tons are discharged. Two-thirds of the contaminants are gases and vapors, with the remainder made up of solid and liquid particulates.

Emissions vary considerably with the seasons. While industrial processing is relatively constant, other activities increase or decrease markedly during the year. For example, the heating load is greatest in winter. Airborne dust from plowed fields and agricultural sprays increase in spring and summer. The ragweed pollen burden is greatest in late summer. Refuse production doubles in summer, and gasoline evaporation increases substantially. In autumn, leaf and brush burning are seasonal air contamination problems.

Twenty-nine percent of Greater Elmira's wintertime air contamination is from industrial plants, but on a year-round basis 40% of the contaminants are industrial in origin.

Annually, private sources account for one-third of all emissions; in the heating season, however, two-fifths of the contaminants come from private activities. In winter, private sources contribute the most contaminants in six of the nine survey area communities.

Commercial sources account for 15% of wintertime emissions and 11% of the annual total. Public activities produce 16% on both winter and annual bases, with increased summertime refuse incineration apparently equaling the winter heating load.

This breakdown clearly shows that emissions from all sources combine to create the area's air contamination. Abatement is a community responsibility—a revelation to community offi-

Table I—Percentage of Air Contaminants Emitted by Source Categories

Source Category	Heating Season			Annually		
	Gaseous	Solid	Total	Gaseous	Solid	Total
Commercial	9	6	15	8	3	11
Public	11	5	16	12	4	16
Private	30	10	40	27	6	33
Total Nonindustrial	50	21	71	47	13	60
Industrial	15	14	29	20	20	40
Grand Totals	65	35	100	67	33	100

cials and citizens who saw air pollution only as an industrial problem. Under the revised program plan, whereby sources are divided into only two categories, it is interesting to note that industrial and nonindustrial emissions would be nearly equal.

Suspended particulate values gathered in Elmira as part of the state air sampling network are the only data available for comparison with computed atmospheric contaminant concentrations. The computed "average maximum" particulate concentration is 199 mg/m³ and the average is 100. From August 1 to October 24, 1958, Elmira samples varied from 29.8 to 175 mg/m³, with a mean of 80.6.

Visibility reduction, soiling, odors and solids deposition cause the most common air pollution complaints in Greater Elmira. Intercommunity pollutant travel is troublesome in portions of the area, but air pollution now is a neighborhood, rather than an areawide, problem. Population growth and industrial expansion may create an air pollution problem in Greater Elmira because of its bowl-shaped topography and occasional temperature inversions.

Rules and regulations for the Greater Elmira area, based on findings of the survey, now are under consideration by the board.

The initial portion of the Niagara Frontier survey, the first under the board's priority schedule, is almost completed in Erie county. This border area is larger, more populous and highly industrialized, and generally more complex than the Elmira area.

The field work was begun in February, 1959, and will be finished in the spring of 1960. The complexity of this survey is illustrated by the large number of industrial sources in the area, between 6000 and 7000, some of which are complex within themselves. Included are steel making and allied or satellite plants, refineries, chemical plants, and a wide assortment of light and heavy industry. Associated with this extensive industrial concentration are the problems that are present because of the large population in this area.

As there is a common border with Canada, there are international air pollution aspects. In 1959, the Ontario Provincial Health Department conducted in a portion of Ontario Province a survey similar to the one in Erie County. The field work has been virtually completed. The New York State inventory program plan[3] has been used as a guide in carrying out this activity.

Public Information

Pre-survey press, radio, and television publicity is issued, and conferences with community and industrial officials are conducted to discuss the purpose, objectives and procedures of the study. A public information program keeps the public abreast of developments, and greatly facilitates field work.

Co-operation by industry has been, with little exception, excellent. An impression of industrial co-operation can be obtained from the fact that the Niagara Frontier Process Industries' Committee on Air Pollution, at a meeting with Air Pollution Control Board representatives, suggested changes in a survey questionnaire which not only facilitated data gathering from industrial sources but provided more information than was originally sought. Such encouraging voluntary co-operation is aiding significantly in completeness and accuracy of the surveys.

Data are published in summary form only and in no case are individual statistics or source identities ever divulged.

After a survey and prior to publication of a report, a summary of conclusions and recommendations is made public and is discussed and explained at a series of meetings with local officials, industrial representatives, and the general public.

Summary

Under the New York State Air Pollution Control Board's program, comprehensive area surveys will be made in all sections of the state to evaluate existing or potential air pollution problems. Necessary local or regional rules and regulations, as deemed appropriate, are based on the findings.

Source sampling usually is not undertaken but emission estimates are obtained from fuel and gasoline consumption, refuse incineration, industrial processing, and other sources. Estimates are based on emission values reported for similar operations and activities in published technical literature. Contaminants are classified by type, amount, source category, and community of origin.

Existing meteorological records and topographical information are analyzed to ascertain important influences on each area's air pollution. Effects are determined from past studies, field observations, citizen interviews, and opinions of qualified personnel. Local ordinances and enforcement are reviewed to appraise effectiveness of local control programs.

In the Greater Elmira pilot study, computations of contaminant concentrations agreed favorably with available sampling results.

Public information is an integral part of the program. Publicity before, during, and following surveys apprises citizens of the purpose, progress, and findings. Industries, community officials, and the general public are cooperating in the surveys.

REFERENCES

1. Laws of New York, Article 12-A. Public Health Law, Ch. 931 (1957).
2. A Review of Air Pollution in New York State, New York State Air Pollution Control Board, Albany (July, 1958).
3. Program Plan for the Inventory of Air Contaminant Emissions, New York State Air Pollution Control Board, Albany (1958), revised, mimeographed (1959).
4. Labor Law, Article 1, Section 2, Subdivision 9 and 11.
5. Air Pollution Survey Report—Greater Elmira, New York State Air Pollution Control Board, Albany (1959).

CALENDAR

Nov. 24–26	National Congress for the Prevention of Atmospheric Pollution, 62 Rue de Courcelles, Paris, France.
Nov. 28–Dec. 9	Air Pollution Course, New York University Post-Graduate Medical School, Institute of Industrial Medicine, New York, New York.
Dec. 3	6th Industrial Hygiene and Air Pollution Conference, The University of Texas, Austin, Texas.
Dec. 4–7	Annual Meeting, American Institute of Chemical Engineers, Hotel Statler, Washington, D. C.
June 11–15, 1961	**54th Annual Meeting of APCA, Hotel Commodore, New York, New York.**

400 FRENCH TOWNSMEN PREPARED TO FIGHT GAS

Everyone carries a gas mask in Arance, France. Arance is nestled within 200 meters of a plant treating natural gas from the Lacq field. The gas contains highly poisonous hydrogen sulfide. A few months ago a flame suddenly went out at the treatment plant and 100 workers had to flee. To avoid trouble in the village, the civil defense organization ordered the 400 residents to carry gas masks at all times. Three blasts of an air raid siren is the signal to don the masks.

The DESIGN and PERFORMANCE of the Aerosol SPECTROMETER*

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Introduction

General Purpose

The knowledge of the true constitution and the reaction kinetics of aerosols has been severely limited by the lack of a method of precipitating out of the air-borne state all particles in the diameter range ($5\mu > d > 0.01\ \mu$) and separating them according to their size (or mass), while least interfering with the physical and chemical properties of the particle prior to its separation from the suspending air.

All filtration and impingement processes expose the surface of the particle prior to and after its retention to the shearing action of the passing air stream. It can be assumed that this shear must disturb seriously the dynamic equilibrium of loosely sorbed or condensed components on the particle surface (probably most effective in irritation) whenever they are present.

Of no lesser importance appears a reliable size-classification, since micro-analytic information about the constituents of unclassified precipitates can be seriously misleading; e.g., the presence of a few 1–2 μ-particles can obscure the true nature of thousands in the 0.1 μ-class due to the cubic relation between particle-mass and -diameter.†

The basic purpose is thus to devise a method and realize it with a practicable instrument, which meets these conditions sufficiently well to render the study of the constitution and the stability of natural and synthetic aerosol systems in the sub-micron range possible.

Operating Principle

The solution of the problem is based on the application of high centrifugal acceleration to a continuous laminar flow of the aerosol under conditions which cause the fall-out of the particles to follow Stokes' law[1] at a velocity relative to the air flow so small that the surface shear is negligible.

Such a process discriminates between suspending gas and particles of different sizes not just by the specific gravity difference but by the "Stokes' diameter" of each particle in the air-borne state. This "Stokes' diameter" may differ significantly from its geometrical dimensions or its light scattering (Mie, Tyndall) diameter, but it appears to be by far the most realistic dimensional definition of a particle, because it determines its kinetic properties while air-borne, hence its behaviour in the respiratory tracts, at the eye surface etc.

The practical realization of this principle meets with seriously conflicting requirements:

The flow speed through e.g., a helical or spiral-shaped channel has to be at a low Reynolds' number ($R^* > 800$) to maintain laminar flow conditions. On the other hand, for the extremely small particle masses (10^{-12}–10^{-16} gr) the centrifugal acceleration, if caused by the flow speed through the helix, should be very large, in order to produce a radial velocity component sufficient for the particle to reach the outer wall of the helix within the time of its presence in the channel.

Moreover, the laminar flow condition necessitates the existence of a boundary layer at rest on the channel walls; hence a particle, after entering this layer, will no longer be subject to centrifugal force and it will lose its velocity in radial direction, if its momentum (i.e., mass) is small. Consequently very small particles may never reach the wall, because they cannot penetrate the boundary layer.

This dilemma can be overcome by moving the wall *with* the fluid, i.e., by spinning the helix (or spiral) around its axis of symmetry. Then the flow speed within the channel is independent of the spin velocity, hence the latter can be very large to produce the required centrifugal fields which extend into the boundary layers, while the former can be as small as required for preserving laminar flow.

The basic element of such an instrument is thus a cylindrical or conical rotor, the periphery of which forms a helical groove covered by a flexible foil. The latter seals the groove to an air-tight channel, after operation it is removed from the rotor for the investigation of the particle deposit thereon.

If the time of residence in the channel is sufficient for all suspended particles to reach the outer wall, i.e., the inner foil surface, the deposit thereon represents a complete "size-spectrum" of the aerosol tested, effected by the difference of radial velocity between the large and the small particles: the former are all deposited near the entrance, the latter toward the end of the channel.

The locus of the deposit of each size class is thus determined by the geometry of the channel, the flow rate, and the angular velocity of the cone, that is by factors independently controllable, therefore the measurement of the deposit density along the channel yields

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* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

† The small size fraction would have an at least 10 times larger surface available for catalytic and/or sorptive interaction with the molecular components of the suspending gas—but also a 10-fold larger mobility due to the Brownian movement. Hence the same quantity of an irritating substance occurring either as one 1 μ-particle or as 1000 units of 0.1 μ diameter becomes in the latter case about 10^4 times more available to a physiologically sensitive surface, such as is involved in eye irritation.

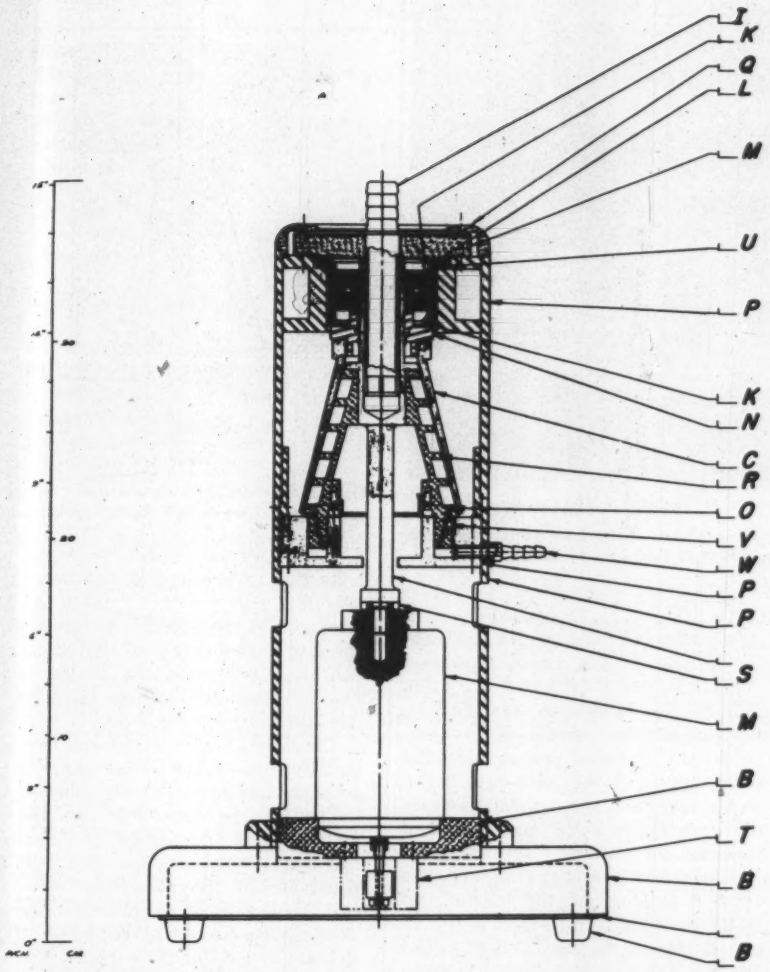

Fig. 1. Vertical cross section of aerosol spectrometer; (R) rotor cone, (C) rotor cup, (N) ring nut, locking, (C) to (R), (P) housing shell, (B) base, (M) lucite Plate, (M) motor driving tachometer (T) and shaft (S); (K, L), "frictionless" bearing assembly; (I) inlet, (O) exchange exchangeable orifices, (V) exit channel, (W) outlet.

the size (and mass) distribution of the aerosol tested, independent from its fate after deposition, because the locus of each particle was determined by its Stokes' diameter, while still in the airborne state.

A considerable advantage of a spinning helix channel is its "self-propelling action" upon the fluid filling it. The momentum imparted by the helix upon the gas causes it to flow along the channel (impeller action) in a sense determined by the direction of the helix and that of its spin. An auxiliary pump for moving the gas through the channel is thus unnecessary.

The flow speed through the channel depends on the pitch of the helix and its spin velocity, however, it can be controlled independently by inserting a flow restriction at the channel exit.

The performance of such a device is obviously determined by the geometry of the rotor: For a *cylinder*[1] the centrifugal acceleration is the same along the entire channel; this causes an unfavorable "dispersion" of the particle sizes, since the deposit of the smallest fraction will cover a much wider range on the channel wall (at lesser surface concentration) than that of the larger fraction. If the rotor represents a *cone*[2] (the channel thus a conical helix of constant pitch and cross section) the centrifugal force increases along the channel due to the increasing radius of the cone. Hence the small particles will be subjected to a larger force than the large particles in case the flow enters on the tip and leaves at the bottom of the cone. This causes a more favorable dispersion for the small sizes.

Construction and Operation of the Aerosol Spectrometer

Design and Dimensions

For this reason a conical rotor type was chosen for the first commercially** available aerosol spectrometer. Its design follows in principle an experimental model previously described,[2] it is, however, more compact and able to separate quantitatively in the 10^{-6} cm-range of particle diameters.

The instrument consists of two separate units, one is the centrifuge, shown in Fig. 1 as vertical cut, the other a chassis with the controls, connected with the instrument by cable. Figure 2 is a photograph of the aerosol spectrometer and its components.

The conical rotor (*R*), in Fig. 1, is made from alloyed aluminum, its outer surface forms $2^1/_2$ turns of a double-helix and represents three of the four walls of two independent, identical channels of uniform (parallelogram) cross section. The channels are sealed by an exactly fitting conical cup (*C*). Its interior surface is lined with an exchangeable foil, which forms the outer wall of the channels where upon the particles are deposited. (*C*) is forced airtight against (*R*) by the ringnut (*N*),

The electric motor (*M*), mounted in the base (*B*), supports and drives the rotor by the shaft (*S*), also the armature (*T*) of an electric tachometer.

At the upper end the rotor is guided by the air-lubricated "frictionless" bearing assembly, consisting of the constituent parts (*I*, *K*, *L*, *U*).

The entire rotor assembly is contained in a heavy, removable shell (*P*), which is sealed on top by a lucite window (*Q*) for stroboscopic observation of the bearing (*K*), in order to check the speed of rotation, independent of the electric tachometer.

The chassis contains a variable autotransformer unit for the speed regulation, volt- and ammeter (for checking the operating conditions of the motor), the tachometer, switch, and fuses (in the primary and the secondary circuit); it is connected by cable and plug with the power supply.

The characteristic dimensions of the instrument are shown in Table I.

Operational Detail

As previously stated, the rotor functions not only as centrifugal separator but also as an impeller for the air through its channels. This combined action causes flow characteristics significant for the operation of the instrument. Figure 3 is a schematic representation of the basic components (analogous to Fig. 1) of the centrifuge for the illustration of the following discussion.

The impeller action of the helix channels is in downward direction since the rotation of the rotor is anti-clockwise and the helix represents a "right-hand" screw. This causes the induc-

** Micronetics Corp., 158 North Kinneloa Ave., Pasadena 8, Calif.

Courtesy: Instrument Development & Mfg. Co., Pasadena, Calif.

Fig. 2. View of the aerosol spectrometer, partly disassembled. Component parts *(from left)*: chassis, cup, housing shell, bearing, motor-rotor assembly, foils (one showing aerosol spectrum).

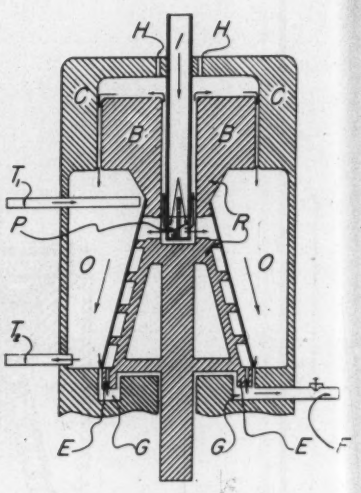

Fig. 3. Schematic cross section of the aerosol spectrometer (arrows indicate flow passages).

tion of air through the ports (*P*) at the upper end of the inner wall of each channel and its propulsion along the helix channels which terminate in the solid ring-shaped base (*E*) of the rotor (*R*). Here the cross section of the channels is restricted by exchangable orifices (*o*) which control the flow rate through each channel independently. The rotor acts thus not only as a centrifugal separator, but also as an impeller.

In order to minimize the disturbance of the aerosol, when entering into (*R*) through (*P*), the air flow is fed through the stationary intake tube (*I*) into the tubular upper end of the rotor by ports at the bottom of (*I*), which meet accurately with the two inlet ports (*P*).††

The outer diameter of (I) is only slightly (cir. 0.02 in.) smaller than the inner diameter of the tubular top of (*R*). Since (*I*) is closed at the bottom and carries vertical vanes within its ports no turbulence is transferred onto the air flow through (*I*), prior to its transfer through (*P*). The horizontal penetration profiles of (*P*) through the inner channel wall are such as to minimize particle separation by impingement at the channel entry.

The air flow leaves the rotor through the orifices into the stationary ring channel (*G*) which leads to the outlet tube (*F*).

The purpose of these precautions is the maintenance of an undisturbed laminar flow of the air during its exposure to the centrifugal field. Experimental evidence indicates this to be attained (c.f.).

Independently, the outer surface of the rotor cup causes, however, a strong vortex of the air within the housing (*o*) and thus a dynamic pressure gradient in radial direction: If 2 tubes (T_1, T_2) are applied to (*o*), (Fig. 3), (T_1) indicates a reduced, (T_2) a proportionally increased pressure, i.e., the outer surface of the rotor acts like a pump, maintaining a dynamic pressure difference between top and bottom of the rotor.

This action causes two effects: The reduced pressure at the narrow end of the rotor causes a fraction of the air sample entering through (*I*) to be sucked through the narrow passages between (*I*)-(*B*), and (*B*)-(*C*), if the top of the housing forms a hermetic seal. If the same were true at its base, this flow through (*I*)-(*B*)-(*C*) should cease almost entirely when the pressure balance between bottom and top is reached. However, the space (*o*) communicates with the outside by the gap (*G*)-(*E*) and the exit tube (*F*), as well as with the motor.

In other words, the action of the conical rotor is equivalent to two parallel air impellers of different pumping capacity with common in- and outlets: one promotes the flow through the channels controlled by the orifices therein, while the other by-passes the cone and is limited by the narrow space between the internal surfaces (*G*)-(*E*). Although this by-pass does not affect at all the particle separation and their size classification in the channel, it can cause significant errors in the indication of the flow rate, for they can be larger than the flow through the channels, it also can contribute air to the outflow at (*F*) which has not passed through the channels.

This situation can be corrected quite simply as follows: A series of small holes (*H*) perforating the top housing near (*I*), with a flow resistance small compared to the gap (*I*)-(*B*), prevents the flow therethrough, so that the inflow at (*I*) represents truly the channel flow and the outer flow into (*o*) is supplied through the holes (*H*).

The flow balance in (*G*) can be established by inserting a valve into (*F*), as an adjustable flow barrier by which the outflow can be reduced to the inflow with suitable flowmeters (c.f.). In this case the dynamic pressure in (*G*) equals that in the space above (*D*), so that no flow from (*o* into G) occurs. This can be assured by adjusting (*F*), so that the flow into (*I*) is slightly larger than the outflow at (*F*), for a small fraction of the channel flow passes from (*G*) into (*o*). One can also reduce the

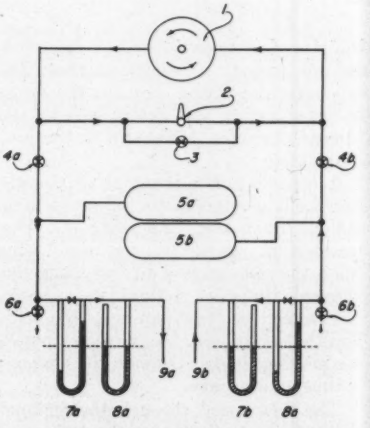

Fig. 4. Schematic diagram of flow-meter-assembly with resistance compensation (1) rotary pump, (2, 3) flow shunts, (4, 6) valves for flow adjustment, (5) buffer tanks, (7) flow gauges, (8) manometers, (9) connections with aerosol spectrometer, (a) refers to the inflow, (b) to the outflow circuit.

†† The reason for meeting three ports on (*I*) with two ports on (*R*) is to avoid an acoustically objectionable siren effect.

Table I

Motor:
Brush-type, ac or dc 135 V max, 1/4 HP, max speed 26,000 rpm = 433 rps

Rotor:

height:	2.63″ (= 6.68 cm)
half-angle of cone (α):	15°
pitch (per full turn):	1.085″ (= 2.76 cm) per turn
turns (n):	2.5 (= 5π)

Channels:

number of helical channels (ν)	2
horizontal diameters of inner wall at inlet ports (D_1)	1.03″ (= 2.6 cm)
outer wall at inlet ports (D')	1.53″ (= 3.9 cm)
inner wall at outlet ports (D'_2)	2.50″ (= 6.34 cm)
outer wall at outlet ports (D_2)	3.00″ (= 7.62 cm)
width (vertical) of thread (w)	0.128″ (= 0.325 cm)
width (vertical) of channel (b)	0.416″ (= 1.06 cm)
depth (horizontal) of channel (c)	0.250″ (= 0.635 cm)
cross section of channel: [$A = b\,c\cos(\alpha)$]:	0.10 sq. inch (= 0.650 cm²)
overall channel length from: in- to outlet (L_0):	15.9″ (= 40.4 cm)
volume of each channel ($V_c = A\,L_0$)	1.59 cu. inch (= 26.3 cm³)
limiting orifices ("jets"), (one pair each) with bores:	0.02″ (= 0.05 cm) 0.03″ (= 0.075 cm) 0.04″ (= 0.10 cm) 0.06″ (= 0.15 cm)

Table I

N rpm (10^3)	O mil, mm	ON cm/min (10^3)	F lit/min	v_r cm/sec	τ_0 sec	γ_{min} g (10^3)	γ_{max} g (10^3)	d_{max} (μ)	d_{min} (μ)
6	60, 1.5	9	2.48	32	1.27	0.52	1.53	2.7	0.5
12	" "	1.8	4.95	64	0.64	2.08	6.10	2.6	0.38
18	" "	2.7	7.40	97	0.43	4.67	13.75	2.5	0.30
12	40, 1.0	1.2	3.30	42.6	0.96	2.08	6.10	2.2	0.23
24	" "	2.4	6.60	85.5	0.48	8.30	24.50	2.0	0.16
18	30, .75	1.35	3.70	48.0	0.85	4.67	13.75	1.8	0.10
24	" "	1.80	4.95	64	0.64	8.30	24.50	1.7	0.07
24	20, .50	1.20	3.30	42.6	0.96	"	"	1.2	0.025

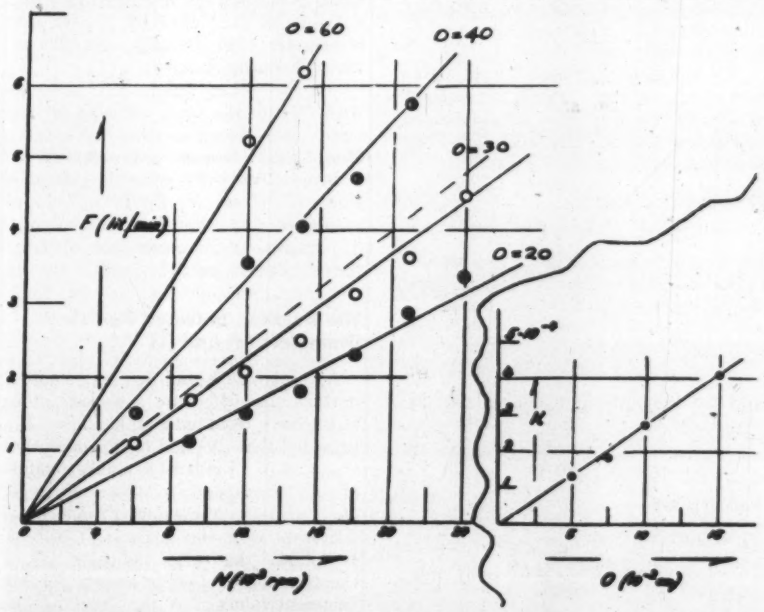

Fig. 5a,b. The relation between flow (F), angular velocity (N) and orifices (O). (a) right: F(N), (b) left: F/N = K(O

pressure build-up by vents such as (T_2) at the bottom of the housing. This renders the pressure control in (F) less critical though still necessary.

Determination of In- and Outflow

The determination and adjustment of the flow (F) through the rotor is of major significance for the interpretation of the size spectrum. The propulsion of the air mass in the channels being due to the dynamic effect of the impeller action causes the flowrate to be quite sensitive to pressure differences between the in- and outlet of the instrument. Special precautions are thus necessary for determining (F), for most metering devices impose flow-restrictions on the system, hence their indications are not representative of the (true) (F)-values for unrestricted flow. It was thus necessary to devise an assembly which compensates the resistance of the flowmeters at the in- and outlet of the instrument.

Figure 4 shows the schematic setup: A small rotary pump[1] activates a constant air flow, as indicated by the arrows. The air flow is "shunted" by a cross connection, the flow resistance of which is adjusted by the valve (3) if the cock (2) is closed. (2) is only open at the start of (1) to avoid pressure shocks in the system. Parallel with this "shunt" are two identical, mutually independent systems ("a" and "b"), passed by the flow in opposite direction. The valves (4a, b) permit the independent adjustment of the flow rates, the containers (5a, b) buffer the pulsations of (1), while the valves (6a, b), represent adjustable air "leaks." The flowmeters (7a, b) indicate (F) by the pressure difference across calibrated (identical) flow restrictions with liquid "U-tube" manometers while the manometers (8a, b) indicate the pressure difference at (9a, b) relative to the atmospheric pressure. (9a) leads to the inlet, (9b) to the outlet of the instrument by tubes sufficiently wide to render their flow resistance negligible.

Evidently, if the adjustment of the air flow is such that (8a, b) show no pressure difference, (7a, b) indicate the in- and outflow (F_i, F_0) for the complete absence of flow restrictions, i.e., the pump activates a system of "negative" resistances, which can be independently adjusted to balance the "positive" resistance of the metering etc. devices at the in- and outlets of the instrument.

A compact metering unit of this design facilitates the adjustment of the outflow restriction (see 2b) for equalizing (F_i) and (F_0) under all operating conditions. For many applications which do not require extreme accuracy, the adjustment of (F_0) can be accomplished by the insertion of another set of calibrated limiting orifices into the exhaust tube (F in fig. 3). The flow resistance of each such orifice reduces (F_0)

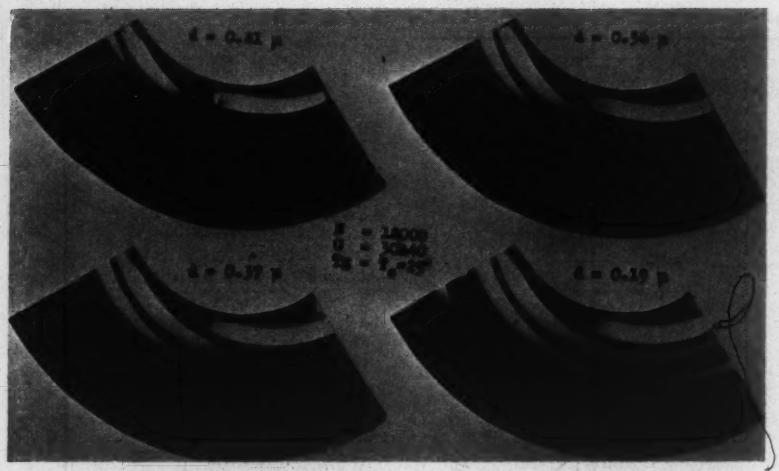

Fig. 6. Photographic reproduction of typical foil deposits from latex aerosols of defined particle diameter (d), indicating the values of (L_d) corresponding to the variation of (O) and (d).

to become equal (or slightly smaller) than (Fi) for a particular standard mode of instrument operation. Five different, exchangeable orifices are required for the combinations of (N) and (o) indicated in Table I and Fig. 7.

Relation Between Operating Factors (F, v_r, N, o, τ_0)

Important for the analysis of the performance of the instrument is the quantitative variation of the flow rate (F), the flow velocity (v_r) through-, and the residence time (τ_0) within a channel with the velocity of the rotor (N) and the aperture of the orifices (o). The relation between (v_r), (F), (τ_0) is simply derived from the dimensional data, given above (2a). They result for: the flow velocity relative to the channel in:

$$v_r(\text{cm/sec}) = \frac{F \cdot 10^3}{60 \cdot \nu \cdot A} = 12.9 \cdot F \quad (1)$$

(F = air flow in liter/min)

the corresponding Reynolds' Number in:

$$R^* = \frac{\rho}{2\eta} \cdot v_r(b+c) = 5.66\, v_r = 73 \cdot F \quad (2)$$

the *time of residence* in the channel in:

$$\tau_0(\text{sec}) = \frac{\nu \cdot V_c \cdot 60}{F \cdot 10^3} = \frac{3.15}{F} \quad (3)$$

and the *time of residence of a particle* in the channel *prior to its deposition* at the distance (L) from the channel entry in:

$$\tau_L(\text{sec}) = \tau_0 \cdot L/L_0 = 2.48 \cdot 10^{-2} \cdot \tau_0 \cdot L \quad (3a)$$

(N) is related to the centrifugal acceleration [in terms of $\gamma \cdot g$, as multiple of the gravity constant (g)] for the rotor diameter (D) as:

$$\gamma = \frac{2 \cdot \pi^2}{9.8} \cdot 10^{-2} \cdot D \cdot N^2 \text{ (for } D\text{, in cm; } N\text{, in rps)} \quad (4)$$

so that each rotor velocity relates to a minimal ($\sim D_1$) and a maximal ($\sim D_2'$) value of ($\gamma \cdot g$), since:

$$\left.\begin{aligned} \gamma_{min} &= 2 \cdot 10^{-2} \cdot D_1 \cdot N^2 = 5.2 \cdot 10^{-2} \cdot N^2 \\ \gamma_{max} &= 2 \cdot 10^{-2} \cdot D_2' \cdot N^2 = 1.52 \cdot 10^{-1} \cdot N^2 \\ \frac{\gamma_{max}}{\gamma_{min}} &= 2.94 \end{aligned}\right\} \quad (4a)$$

The variation of (F) with (N) has to be determined experimentally, it should be linear if the flow is caused by momentum transfer from the rotor, i.e., by an impeller action and if laminar conditions prevail.

Figure 5a shows the variation of (F) with (N), as obtained with the described (2c) flowmeter assembly, for ($F_t = F_0$), over a wide range of (N), with four different orifice diameters (o = 1.5, 1.0, 0.75, 0.50 mm).

The functions indicate a linear variation within the error margin for each set of orifices. Hence: $F = \kappa \cdot N$, and since (κ) varies also linearly with (o) (Fig. 5b), it follows that:

$$F = \sigma \cdot o \cdot N \ldots \text{ and: } \sigma = \kappa/o = 2.75 \cdot 10^{-3}\ (\text{cm}^2) \quad (5)$$

for F as lit/min; o as cm; N as rpm.

For the relative flow velocity through the channels results thus (eq. 1):

$$v_r = 12.9 \cdot \sigma \cdot o \cdot N = 3.55 \cdot 10^{-2} o \cdot N (\text{cm/sec}) \quad (6)$$

and for the time of residence (eq. 3):

$$\tau_0 = \frac{3.15}{\sigma \cdot o \cdot N} = \frac{1.15}{o \cdot N} \cdot 10^3\ (\text{sec}) \quad (7)$$

and (eq. 3a):

$$\tau_L = 2.48 \cdot 10^{-2} \cdot \tau_0 \cdot L = \frac{2.85 \cdot 10^1 \cdot L}{o \cdot N}\ (\text{sec}) \quad (7a)$$

These relations hold for both channels independently, regardless of whether they carry identical or different orificies.

Noteworthy is the following relation if two different orifices (o_1, o_2) are operated simultaneously: If ($Z = Z_1 + Z_2$) is the total particle concentration in the aerosol tested, and (Z_1, Z_2) the fractions which flow through the channels with the respective orifices (o_1, o_2) it follows from (eq. 5) that:

$$F_1/F_2 = o_1/o_2 = Z_1/Z_2$$

and from (eq. 7) for the respective time intervals available for sedimentation in the channels:

$$\tau_{01}/\tau_{02} = o_2/o_1 = Z_2/Z_1$$

i.e., the interval is the larger, the smaller the fraction of the sample passing the channel.

If one could assume the same rate of sedimentation (for a monodisperse aerosol) in both channels (i.e., $\tau_{L_1} = \tau_{L_2}$) the deposit concentrations (number of particles per unit area, defined as: ($C_1 = Z_1/L_1$; $C_2 = Z_2/L_2$) must be the same in both channels and independent from (o), since:

$$\frac{L_1}{v_{r_1}} = \tau_L = \frac{L_2}{v_{r_2}} \text{ and: } \frac{C_1}{C_2} = \frac{Z_1}{Z_2} \cdot \frac{v_{r_2}}{v_{r_1}} = \frac{Z_1}{Z_2} \cdot \frac{o_2}{o_1} = 1$$

This is, however, not true, because the conical form of the helix causes the sedimentation rate to increase with (D) (eq. 4) and thus with (L), so that (τ_L) decreases with increasing values of (v_r, o, and/or N). It follows that for any specific aerosol the maximal value of (C) (i.e., the minimum of sampling time) is reached for any given (N) with a value of (o), whereby the deposit terminates close to (L_0), i.e., fills almost the entire channel.

On the other hand, (C) increases with (N) for the same value of (o), because (L_d) decreases with (N) (c.f.). Hence the largest concentration is always effected with the largest (N), since: $C_1/C_2 = N_1 L_2/N_2 L_1$. Large values of ($N$) though produce small dispersions, i.e., decrease the differentiation between particle sizes.

The Relation between Particle Diameters (d) and (L)

Aerosols with a defined smallest particle size (d) cause a deposit along (L) which terminates for ($L = L_d$), provided that (N) and (o) are such that ($L_d < L_0$). Evidently, smaller values of (d) correspond to those of larger (L_d), while for the same (d)-value (L_d) decreases with increasing (N) or (τ_0). It follows that (L_d) indicates (d), if the function [$d(L_d)$] is known for the pertinent values of (N, o).

Due to the complexity of the physical conditions in the channel a theoretical

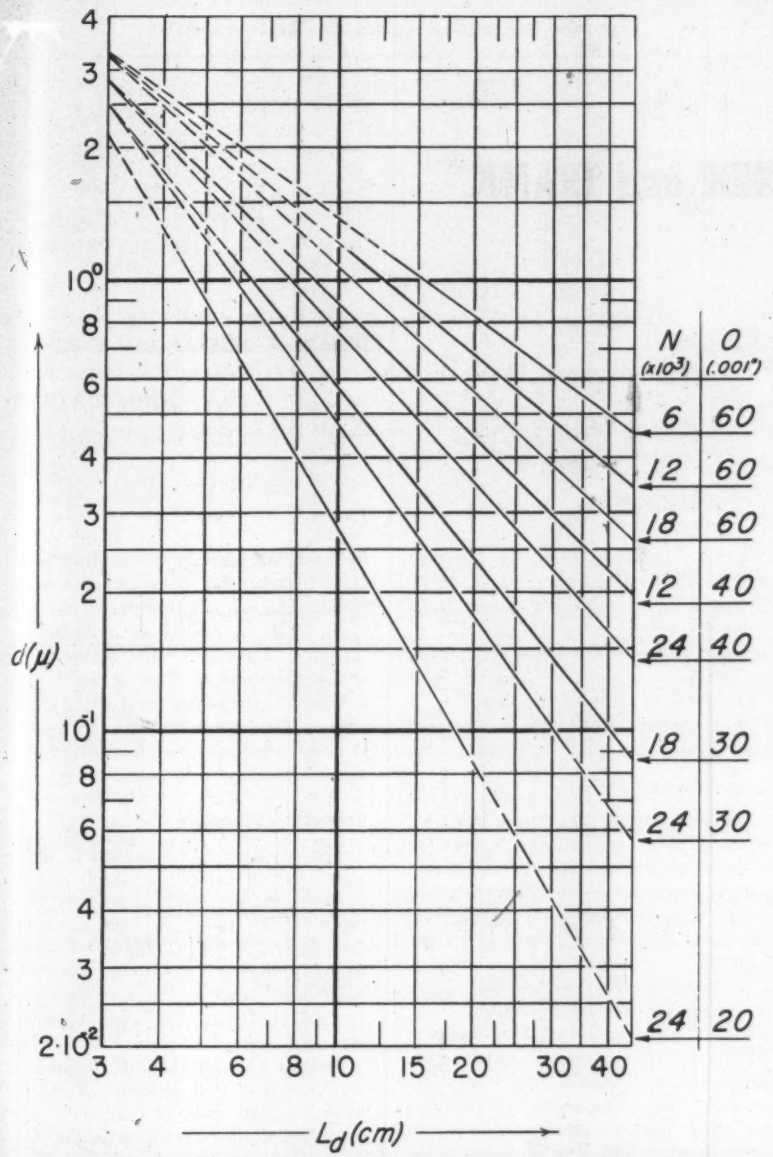

Fig. 7. Particle diameter (log d) vs. corresponding length (log L_d) for different operating conditions (N, O) of the aerosol spectrometer. (Solid line sections refer to the (d)-range calibrated with latex aerosols, hatched line sections to their linear extrapolation.)

determination of this function appears less reliable than an empirical calibration with aerosols, produced with polystyrene latex available in uniform shape and defined diameter in the range ($1.2\ \mu \geq d \geq 0.088\ \mu$). Aerosols, obtained by nebulizing dilute aqueous suspensions of such particles, are not monodisperse, but rather multidisperse, for they consist of a variety of discrete sizes, due to unavoidable agglomeration of the individual particles, however, they have a defined minimum size (d) represented by the fraction of particles which are not agglomerated. Figure 6 shows photographs of such foil deposits resulting from aerosols of different (d) obtained for different values of (N, o), they indicate the sharp termination of the deposit at the respective (L_d).

The function $[d(L_d)]$, obtained from calibration with latex aerosols of 8 different sizes approximates a straight line in log.-co-ordinates, its slope increases with (N) and decreases with (o).

Figure 7 represents $[d(L_d)]$ for a variety of (N, o) values, selected for the uniform coverage of the range of (d) and (L). The calibration refers to operating conditions of the instrument with the (F)-values in Fig. 5 resulting from eq. (5).

The range of (d), covered by a particular set of operating conditions, varies largely with (N) and (o), i.e., with the slope of each line.

Figure 7 indicates the size ranges, actually calibrated with latex aerosols, as solid lines, while the linear extrapolation corresponds to the hatched sections of each line. They indicate the uncertainty—i.e., the experimentally unproved validity of the linear extrapolation—for the ranges ($d < 0.08\ \mu$) and ($d > 1.2\ 9$). During recent months a monodisperse polystyrene latex of ($d = 2.85\ \mu$) has become available. Its use for calibration proved the adequate validity of the upper hatched sections for ($d > 1.2\ \mu$). Similarly uncertain is the validity of the linear relation for ($L_d \leq 4$ cm) due to the initial disturbance of the flow after entry into the channel and at the approach to the orifices, i.e., for ($L_d \geq 38$ cm).

This limits the range of (d) for the (N, o)-values tested to ($d_{max} \leq 3\ \mu$ for $N = 6{,}000$, $0 = 60$) and ($d_{min} \geq 0.03\ \mu$ for $N = 24{,}000$, $0 = 20$). The (d)-range accessible to analysis embraces thus the factor of about 100, and the corresponding range of particle masses of about one million.

The following table correlates the values of (F, v_r, τ_0, γ_{min}, γ_{max}, d_{min} and d_{max}) with the corresponding values of (N, o) in the $[d(L_d)]$ diagram. (Fig. 7).

The table permits the selection of the optimal operating conditions (N, O) for the specific test requirements. The largest sampling rate is obtained for ($N = 18{,}000$, $O = 60$) which corresponds to a Reynolds' number (eq. 2) of ($R^* = 710$). The use of the same (O) at ($N = 24{,}000$) would increase (F) to 10 lit/min and bring (R^*) close to 10^3, thereby disturbing the laminar flow.

The maximal value of (N) obtainable with the instrument is about 26,000 rpm producing ($\gamma_{max} = 30{,}000$ g).

Conclusion

The Aerosol Spectrometer effects thus the quantitative separation and the deposition of air-borne particulate matter in a pattern, which is geometrically defined over a size range controllable by the operating conditions between Stokes' diameters of 3μ to 0.03μ. The derivation of the size- and mass-distribution in polydisperse aerosols from such deposit patterns, requires procedures which are described in detail in another paper.

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(*Continued on p. 414*)

LEAD, CARBON MONOXIDE *and* TRAFFIC*

A Correlation Study

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During the course of a study on the contribution of engine exhausts to air pollution, information was obtained on the monoxide and particulate lead concentrations in the atmosphere of a northeastern metropolitan city. The traffic density at each sample location was also obtained. The results showed high correlation between traffic density, average carbon monoxide concentration, and average particulate lead concentration.

A review of the literature showed that little work had been done on the relationships between these variables. Lykova,[22] Effenberger,[10a] and Clayton[9a, 9b] compared carbon monoxide and traffic density while Tufts[34] compared lead in air with traffic density. Their results are described in the discussion of the correlations evolved.

The carbon monoxide concentration for urban areas,[7] Cincinnati,[5] Detroit,[3, 9b] Los Angeles,[4, 16, 20, 24, 30] New York,[17] Baltimore,[4] Donora,[4] Salt Lake City,[4] Santa Clara,[31] London,[25, 35] Paris,[23] Milan,[12, 13] Naples,[15] Rome,[10] West Germany,[10a, 27] Brussels,[14] and Soviet cities[22] showed that the concentration in the air ranged from <1 to about 100 ppm. However, on occasion in heavily congested traffic, the CO level was reported as high as 500 ppm. Average CO levels in the cities tested were for the most part below 15 ppm. In tunnels in New York,[33, 36] other large U. S. cities,[1] and Berlin,[27] the carbon monoxide level reached upwards to 300 ppm with mean levels of about 70–100 ppm.

The atmospheric lead concentrations measured (including tests in tunnels) in Cincinnati,[4, 5, 29] Detroit-Windsor,[8, 9, 26] Chicago,[34] Los Angeles,[6, 16, 21, 29, 30] New York,[29] numerous other U. S. cities,[4, 29] a Michigan county,[2] Milan,[12, 13] Zurich,[28] and Switzerland[18] had a range of <1 to 27 mmg/cu m. Lead concentrations below 10 mmg/cu m were most common. In garages, the level reached was as high as 60 mmg/cu m.[19] A peak level of 18.8 mmg/cu m was reported[28] in a tunnel through which about 12 cars/min passed.

Experimental

Traffic density was obtained by physically counting, using a manual counter, all the cars and trucks passing sample location for 5–10 min each half hour during the eight-hour sample day. The data are presented in vehicles per minute.

Particulate lead was obtained by metering air through a rotameter at about 10 l/min and then through a Millipore molecular sieve filter paper, unbacked, in a closed filter holder assembly. The total weight of the lead collected was determined colorimetrically by a dithizone procedure similar to that described by Elkins.[11] The results are calculated in mmg/cu m.

Carbon monoxide concentration was determined in a partially continuous manner similar to that outlined by Shepherd, et al.[32] This was done by metering air through a rotameter at a constant rate of about 100 cc/min through a silica gel trap and then into three commercially available carbon monoxide indicator tubes in parallel. The color developed, which varies from yellow to dark green, is a function of the concentration of carbon monoxide and the quantity of air sampled. By visually matching the shades obtained to a reference color standard and noting the time and sampling rate necessary for the color change, the concentration of carbon monoxide in the air was determined in ppm.

The three tubes in parallel were used as a means of eliminating possible defective tubes, although in the study none were found. The color in all sets of tubes changed simultaneously to the same shade, as closely as could be determined visually. The tubes were changed in sets of three when a predetermined shade was matched. If the color in the tube had not reached a reference standard, the final sample of the day required interpolation.

Sampling Schedule

The schedule was arranged to minimize bias in sampling. Each sample location in the study was used five times. The program was operated five days a week, Thursday through Monday, during a three-week period in July and August, 1959. Sampling started at 10:30 AM and continued through 6:30 PM each day. The Thursday-through-Monday schedule was chosen so that weekend as well as weekday data could be collected. The sampling sequence is shown in Fig. 1.

The stations chosen fell into three categories. Stations 1 and 2 were in high traffic areas, stations 3 and 4 were in moderate traffic areas, and stations 5 and 6 were in light traffic areas. The rows in the chart show that on each day two stations of the six selected were sampled during the three weeks allocated. The columns show that each station was sampled twice in two of the sampling weeks and once in the remaining week.

Sample Location

Factors that were taken into account in selecting the sites included the area of neighborhood, the type and location of nearby industry, location of nearby thoroughfares, density and continuity of traffic flow, electric power availability, shelter, space for instruments, prevailing wind, and direction and location of barriers and buildings. The sam-

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Table I—Traffic Density, Vehicles per Minute

Sampling Day	Station: Heavy Traffic 1	2	Moderate Traffic 3	4	Light Traffic 5	6
Thurs.	61	45	13	14	2	3
Fri.	69	45	15	16	2	1
Sat.	52	39	12	12	2	2
Sun.	42	23	8	7	1	1
Mon.	61	63	14	13	2	3
Over-all Station Avg	57	43	12	12	2	2

Table II—Range of Traffic Density, Vehicles per Minute

Sampling Day	Station: Heavy Traffic 1	2	Moderate Traffic 3	4	Light Traffic 5	6
Thurs.	55–70	32–70	11–22	9–17	1–4	1–5
Fri.	60–99	38–56	10–20	13–18	1–3	1–2
Sat.	32–68	30–46	9–14	9–15	1–3	0–4
Sun.	38–54	16–30	5–11	3–10	0–2	1–3
Mon.	49–79	32–79	10–17	9–21	1–4	1–5
Station Range	32–99	16–79	5–22	3–21	0–4	0–5

Table III—Lead Concentration, mmg/cu m

Sampling Day	Station: Heavy Traffic 1	2	Moderate Traffic 3	4	Light Traffic 5	6
Thurs.	4.74	2.60	1.61	1.31	0.20	0.33
Fri.	3.61	1.91	0.98	0.64	0.55	0.73
Sat.	2.80	2.03	1.50	0.99	0.77	<0.1
Sun.	0.61	0.65	0.60	0.70	0.49	0.61
Mon.	0.77	1.91	1.30	1.05	0.16	0.50
Over-all Station Avg	2.51	1.82	1.20	0.94	0.43	0.43

Table IV—Carbon Monoxide Concentration, ppm

Sampling Day	Station: Heavy Traffic 1	2	Moderate Traffic 3	4	Light Traffic 5	6
Thurs.	16	6	3	2	1	<1
Fri.	9	4	2	1	<1	<1
Sat.	8	4	<1	2	<1	1
Sun.	1	<1	<1	1	<1	<1
Mon.	5	8	2	2	1	<1
Over-all Station Avg	8	4	1	2	<1	<1

plers were set up 30–50 ft from the nearest traffic at about 4 ft above ground level.

Results

The traffic density was averaged from 17 5–10 min traffic counts during the eight-hour day, and the results are shown in Table I.

It is interesting to note the variation in traffic flow for the days of the week. On Sundays, the average traffic flow is reduced by one-third to one-half of the over-all station average. During the weekdays, the average traffic density remains fairly constant.

The ranges of traffic densities are tabulated in Table II. The ratio of the upper to the lower traffic count varies from 1.4:1 to as much as 5:1. For obvious mathematical reasons, these ratios do not consider the ranges with 0 vehicles per minute as the lower limit. The average ratio of range extremities is 2.5:1. The peak traffic flows were generally reached from 4:00–5:30 PM, while the lows were recorded usually from 6:00–6:30 PM.

Lead

The particulate lead concentrations obtained during the sampling program are presented in Table III. These concentrations represent eight-hour averages.

The <0.1 value shown for Saturday at Station 6 was assumed equal to 0 mmg/cu m for calculation purposes. A regression of lead levels on traffic density using the 30 data points obtained yielded the following relation which is positively correlated at greater than 99% significance

$$Pb = 0.444 + 0.0363T \quad (1)$$

where

Pb = lead level, mmg/cu m
T = traffic density, vehicles per minute past the sample location

Equation (1) plus the corresponding 95% confidence limits for the regression of lead concentration on traffic density data are plotted in Fig. 2.

Carbon Monoxide

The carbon monoxide concentration averaged during the day is tabulated in Table IV.

The trend of the 30 data points shows that increased car population is related to increased carbon monoxide content in the air. The regression of average carbon monoxide level obtained each day at each station on the corresponding average daily traffic density gave the following highly correlated relation at greater than 99% significance. For calculation purposes, <1 values in Table IV were assumed equal to 0 ppm.

$$CO = -0.281 + 0.136T \quad (2)$$

where

CO = carbon monoxide, ppm
T = traffic density, vehicles per minute past the sample location

A plot of equation (2) with the corresponding 95% confidence limits for the regression of atmospheric carbon monoxide concentration on traffic density are given in Fig. 3.

The carbon monoxide concentration ranges obtained during the day at each station are shown in Table V. The range of those concentrations with a lower limit of one or greater had a ratio of upper to lower level which varied from 2:1 to 12:1. The average ratio was 4:1. These range figures compare closely with the traffic density ranges described previously.

A further study of the data obtained for carbon monoxide and lead concentrations suggests the possible relation between these variables. The corresponding data in Tables III and IV yielded the following highly correlated regressions of CO on lead and lead on CO.

$$CO = -1.169 + 3.111\ Pb \quad (3)$$

and

$$Pb = 0.516 + 0.268\ CO \quad (4)$$

These regressions are plotted in Fig. 4.

In the above case, carbon monoxide and lead would be expected to be related only through the fact that they are

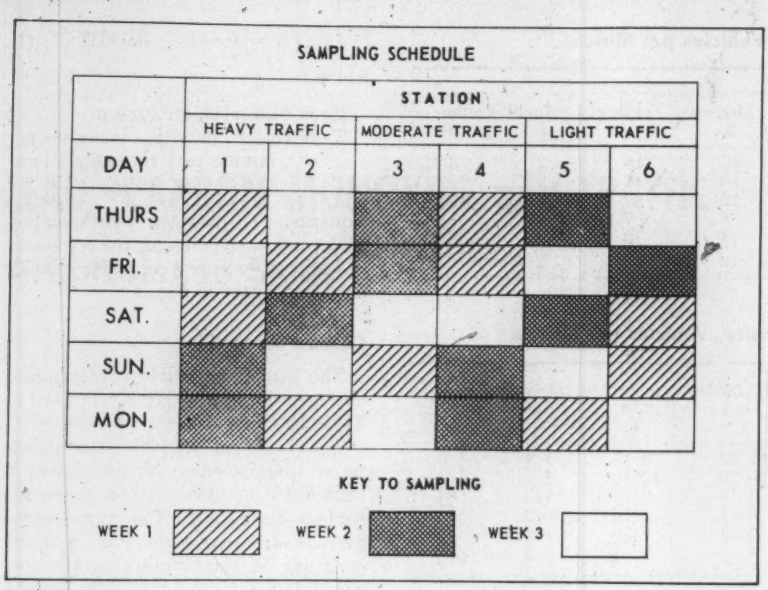

Fig. 1.

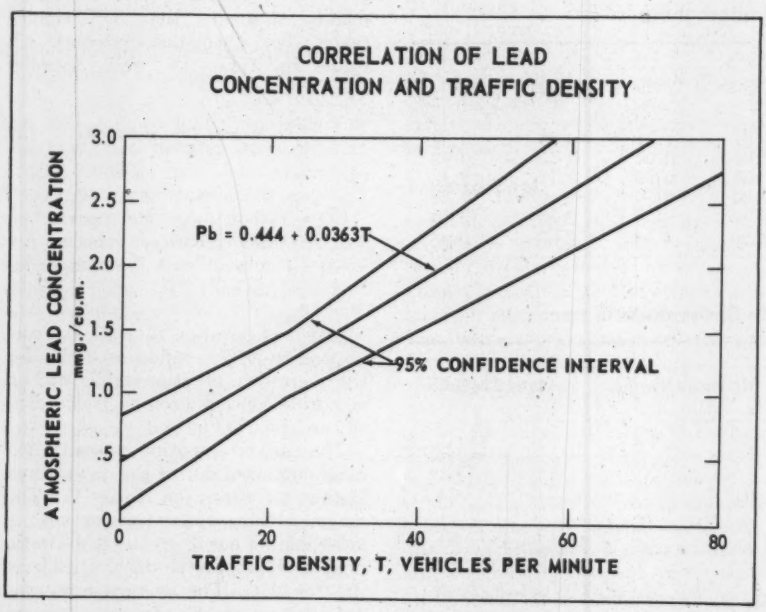

Fig. 2.

emitted from the same source, the automotive engine. The incomplete combustion of gasoline, as in an engine, is a recognized source of carbon monoxide, but unless lead is present in the consumed gasoline, lead would not be expected to be exhausted. However, the fact that most commercially available gasolines do contain tetraethyl lead is evidence a priori of the presence of lead in the exhaust gases from automobiles.

The developed regressions for carbon monoxide and lead then are indicative of air pollution from automobiles consuming leaded-gasolines.

Discussion

Before proceeding with the discussion it is important to remember that the data, the correlations drawn, and the 95% confidence intervals for regressions calculated are all based on tests conducted in one northeastern United States' city. The extent to which the correlations and confidence intervals can be generalized will vary with such factors as meteorology, type of traffic flow, and sampler location.

Weather Effects

Because the testing was done in the summer, the air temperature was generally 80–90°F. At other temperatures, convective currents could be different and might possibly alter the levels obtained. It is expected, however, that the temperature effect would be minimal compared with the others to be discussed.

The wind conditions were generally variable. It is suspected that over the course of three weeks, the direction and velocity ran the gamut of meteorological patterns at the location of the samplers, four feet above the ground. No meteorological data were obtained during the study. Wind direction and velocity obtained from the Weather Bureau were not considered to be directly applicable. Under conditions of high wind turbulence and maximum dilution (not experienced during the tests), the slope of the correlation curves could be lessened so that even under conditions of high traffic density, the levels of lead and carbon monoxide might be less than the lower confidence limits. On the other hand, in an area with predominantly calm wind conditions, the slope of the correlations might be greater than that shown.

The distance the sampler is placed from the traffic stream is an important factor in the detection of air contaminant levels. In the subject study, 30–50 ft was used. At other distances, correlations would still be expected to evolve but with the location and slope of the curve changed.

Traffic Effects

Traffic patterns are also quite important. Little congestion was found to exist at the six stations tested; that is, traffic flow was relatively free flowing, and therefore, density measurement in cars per minute should be representative of the number of cars exhausting in the proximity of the samplers. If in another area it was found that traffic pile-up was commonplace, cars per minute past the sampler might not be truly indicative of the number of car exhausts near the sampler. In this case, a more proper assessment of traffic density might be cars per 1000 ft^2 near the sampler. This type of count would be very difficult to obtain. Time-lapse photography might be used to collect such data.

To generalize, the results of this study point out the importance of traffic density in relation to the lead and carbon monoxide in the atmosphere. More detailed generalizations, without accounting for the factors discussed above, might suggest erroneous levels of lead and carbon monoxide based on traffic data. Perhaps if more data were available, the correlation developed in the one city tested could be adjusted for these factors. Therefore, for a full-scale assessment of traffic and its relation to contaminant levels in the atmosphere, more data are necessary. It would be advisable that future work in this field include traffic density data, along with the information on the factors discussed, when reporting possible vehicle-related atmospheric contaminants.

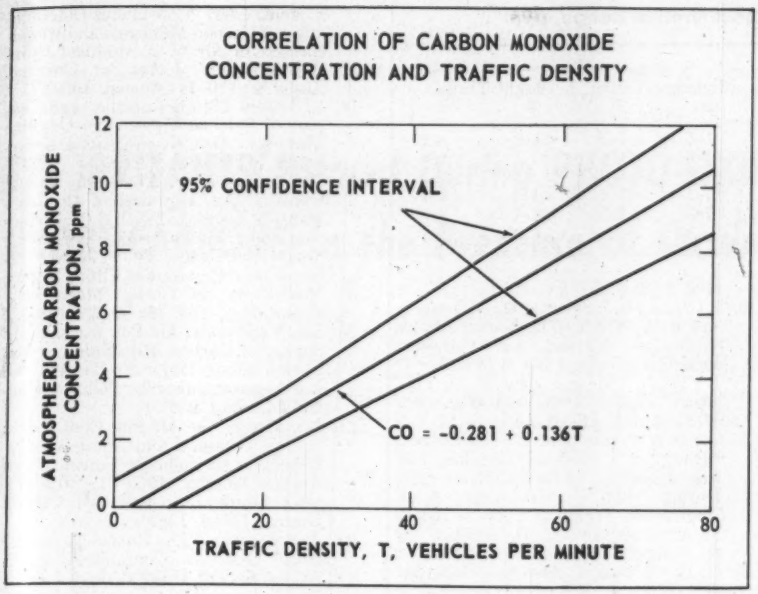

Fig. 3.

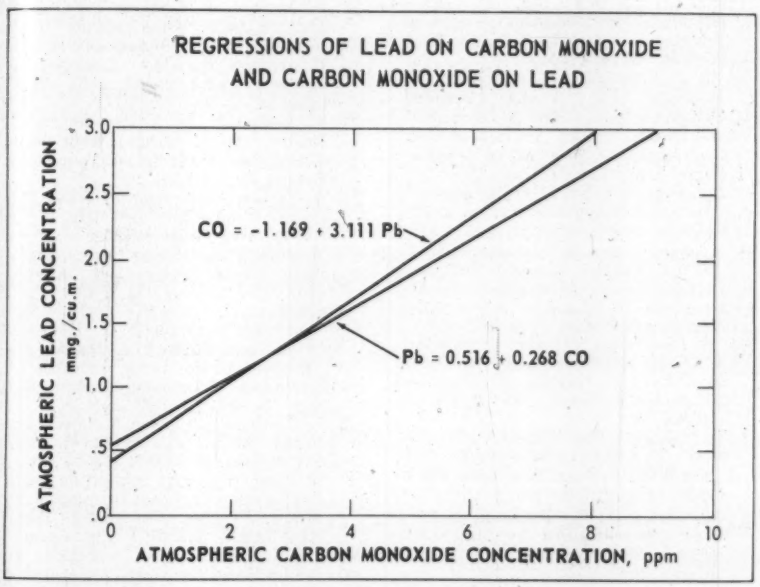

Fig. 4.

Data from Literature

Many authors have pointed out that carbon monoxide and lead are directly related to traffic. Unfortunately, the data presented are usually only qualitative. However, some authors have presented actual data which will now be discussed.

Lykova[22] compared traffic density with carbon monoxide concentration in the street air of certain Soviet cities. The data Lykova presented are 5, 11, and 22 ppm carbon monoxide for <17, 17–25, and 25–50 vehicles per minute, respectively. The mean levels of carbon monoxide obtained in the Soviet cities tested were about two to three times higher than those obtained during the subject study. Lykova's work being done in 1953 in the Soviet Union could reflect differences in Soviet vehicles and gasoline from the automotive situation in the northeastern United States' city tested in 1959. Further evaluation of the variance suggests that the sampler location, being closer to the traffic in the Soviet cities, could contribute to the explanation of the differences noted.

Berlin

Effenberger[10a] found that carbon monoxide at the breathing zone of customs officials and traffic density at border crossing points in Berlin are highly correlated. Regressions of carbon monoxide on traffic density at two different locations gave the following relations:

$$CO = -37.2 + 30.0T$$
$$CO = +6.6 + 20.2T$$

where

CO = carbon monoxide concentration, ppm
T = traffic density, cars/min

Effenberger points up the differences in these regressions to differences in meteorology that existed at the time of the sampling and to the types of buildings near each location.

In periods of heavy traffic with little wind, peak values of 220–240 ppm CO were measured. Average values of about 78 and 130 ppm CO were encountered at the two stations tested. The range of traffic densities encountered in Effenberger's study was from 1–8 cars/min. The differences in the levels of CO obtained by Effenberger and obtained in the subject study can be almost wholly attributed to the distance between the CO sampler and the automobile. Customs officials in processing the cars through their check points stood in quite close to the vehicles. The fact that the cars were idling while awaiting customs processing would also tend to increase the levels of CO.

Detroit

Clayton[9a,9b] collected data in Detroit on carbon monoxide, traffic density, and meteorological conditions. Statistical treatment of these data is now being made to develop, if possible, a mathematical model which would include carbon monoxide, wind speed, air temperature, traffic density, inversion information, and time of day.

Chicago

Tufts[34] compared lead concentration with street traffic density. The air was sampled with Millipore molecular sieve paper in a small shopping district in Chicago. Samples which were obtained were treated for microscopic examination, and the lead particles collected were counted and sized. Sampling was done in 10-min intervals over about a two-hour period. An estimate was made of the mass of lead collected (based on lead chloride) in each sample from the particle count and size distribution. The results in mmg/cu m were compared with traffic counts which varied from four to seven vehicles/minute. The lead levels obtained by these calculations were considerably higher than would be expected from the correlation of lead level in traffic obtained in the subject study. It should be noted, however, that Tufts sampled within two feet of the traffic at about three feet above the ground. The close proximity to the traffic could explain the higher level obtained. Possible

Table V—Carbon Monoxide Concentration Range, ppm

Sampling Day	Station: Heavy Traffic 1	Heavy Traffic 2	Moderate Traffic 3	Moderate Traffic 4	Light Traffic 5	Light Traffic 6
Thurs.	7–47	2–13	1–5	1–4	<1–1	<1
Fri.	7–14	2–6	1–3	<1–2	<1–1	<1–1
Sat.	3–16	2–7	<1	1–2	<1	<1–1
Sun.	1	<1	<1–1	<1–6	<1–1	<1–1
Mon.	1–12	5–13	1–3	1–3	<1–1	<1
Station Range	1–47	<1–13	<1–5	<1–6	<1–1	<1–1

errors in the estimation technique used could also contribute to the deviation noted in Tufts' results.

In the city tested, there was no apparent industrial source of carbon monoxide or lead. If such a source is present, e.g., a lead smelter, obviously the atmospheric level of the contaminant could be expected to increase beyond vehicle exhaust producted levels. Sources other than vehicle exhaust must then be considered in any analysis of data relating the particular variables discussed in this report.

Summary

Atmospheric levels of lead and carbon monoxide were studied at six locations in a northeastern United States' city, wherein the traffic density varied from 0–99 vehicles/min. Positive correlations have been developed between lead and traffic density and between CO and traffic density. The correlations obtained conclusively point to vehicle exhaust as a source of lead and carbon monoxide in the atmosphere.

Acknowledgment

The author would like to thank N. V. Hendricks, and W. H. Meyer of Esso Research and Engineering Co. for their co-operative efforts in collecting the field data.

Also, thanks are due F. W. Wehrfritz of Esso Standard Oil Co. for his assistance in setting up the sampling schedule and in the statistical evaluation of the results.

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(*Continued on p. 413*)

EYE IRRITANTS *Formed During* PHOTO-OXIDATION OF HYDROCARBONS *in the Presence of Oxides of Nitrogen*[*]

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Eye irritants are formed when certain mixtures of hydrocarbons and oxides of nitrogen are irradiated with near-ultraviolet light. Eye irritation is not detected in these mixtures prior to irradiation; thus, the irritants are products or intermediates of the photo-oxidation. The purpose of this investigation was to identify the products of the reaction and to relate these products to observed eye irritation. This work was carried out at Stanford Research Institute under the sponsorship and with the support of the Air Pollution Foundation and the National Institutes of Health.

Experimental Techniques

Each mixture studied was composed of purified air 1† to which was added 3 to 6 ppm of a hydrocarbon and 1 to 2 ppm of nitric oxide or nitrogen dioxide. These mixtures were prepared and irradiated in the 520-cu-ft chamber shown in Fig. 1. Irradiation was provided by 24 mercury arcs and 78 Blacklite fluorescent bulbs. The near-ultraviolet intensity in this chamber was approximately equal to noonday sunlight as measured by photolysis of nitrogen dioxide in nitrogen.

The reactions were monitored at 12 to 15 minute intervals with a long-path infrared spectrophotometer from 2 to 14 microns during a 2-hr irradiation period. Thus time-concentration records of reactants and products were obtained. Examples of the infrared spectra before and after photo-oxidation are shown in Figs. 2 and 3. A typical time-concentration graph constructed from the infrared spectral data is shown in Fig. 4. It was possible to identify products by reference to published spectra and by calibration of the spectrophotometer with the suspected products. Additional analysis of the gas mixtures with a gas chromatograph aided in these identifications. After the 2-hr irradiation period the mixture was piped to eye irritation booths (Fig. 1) where human test subjects reported the degree of eye irritation they experienced.

The subjects reported irritation every 30 sec for a period of 5 min in terms of none (0), light (1), medium (2), or severe (3). The numbers assigned to these reports were used to calculate the eye irritation index for the panel. The resulting indices were assigned the following interpretations: 0 to 6, none to light irritation; 6 to 10, light to medium irritation; 10 to 16, medium to severe irritation and above 16, irritation of sufficient severity to cause lachrymation in more than 50% of the subjects. Maximum possible irritation was 24.

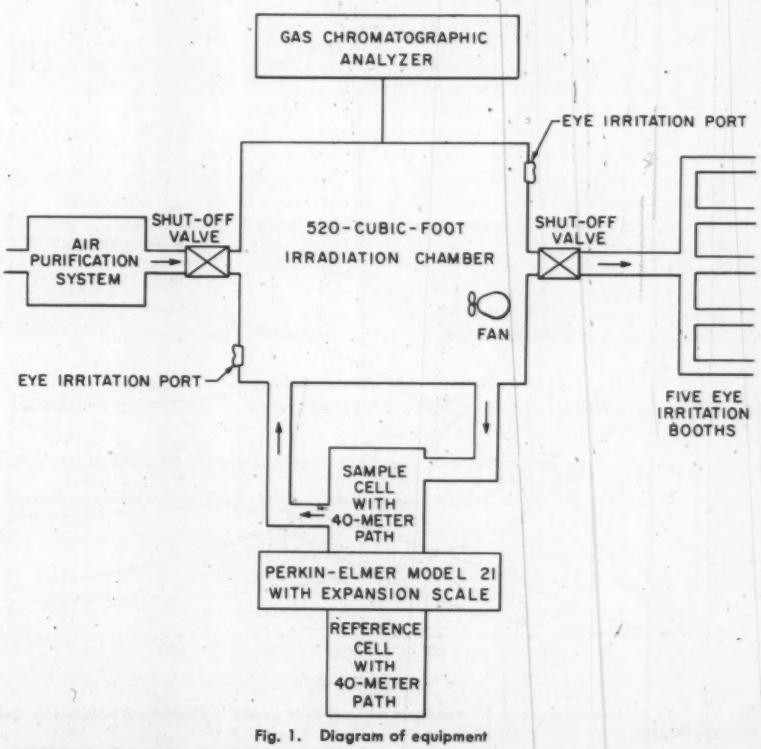

Fig. 1. Diagram of equipment

[*] Presented at the 53rd Annual Meeting of APCA, May 22–26, 1960, Netherland Hilton Hotel, Cincinnati, Ohio.

† This purified air was obtained by passing atmospheric air over a platinum catalyst at 1000°F and filtering through charcoal. This air contained less than 0.1 ppm of hydrocarbon and less than 0.1 ppm of nitric oxide or nitrogen dioxide.

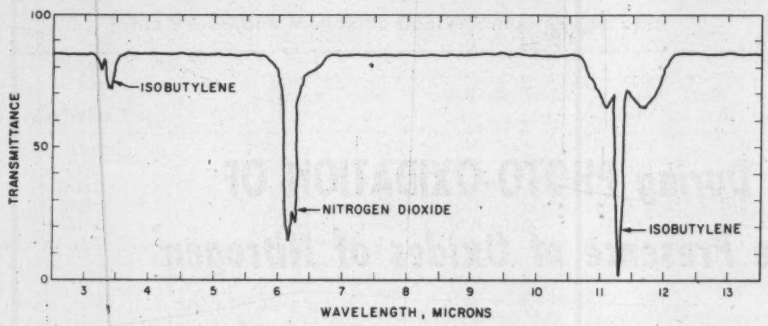

Fig. 2. Infrared spectrum of 3 ppm isobutylene and 1 ppm nitrogen dioxide before irradiation.

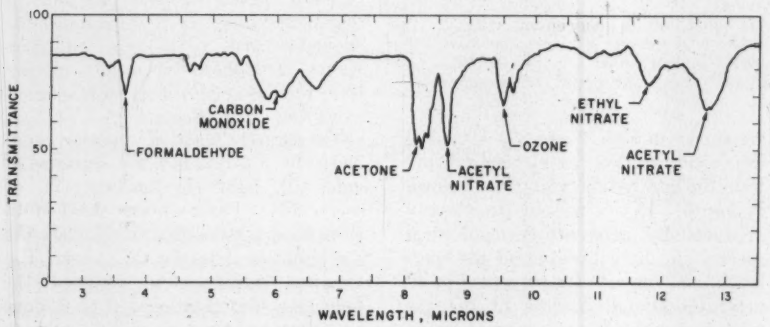

Fig. 3. Infrared spectrum of products after 2-hr irradiation of 3 ppm isobutylene and 1 ppm nitrogen dioxide.

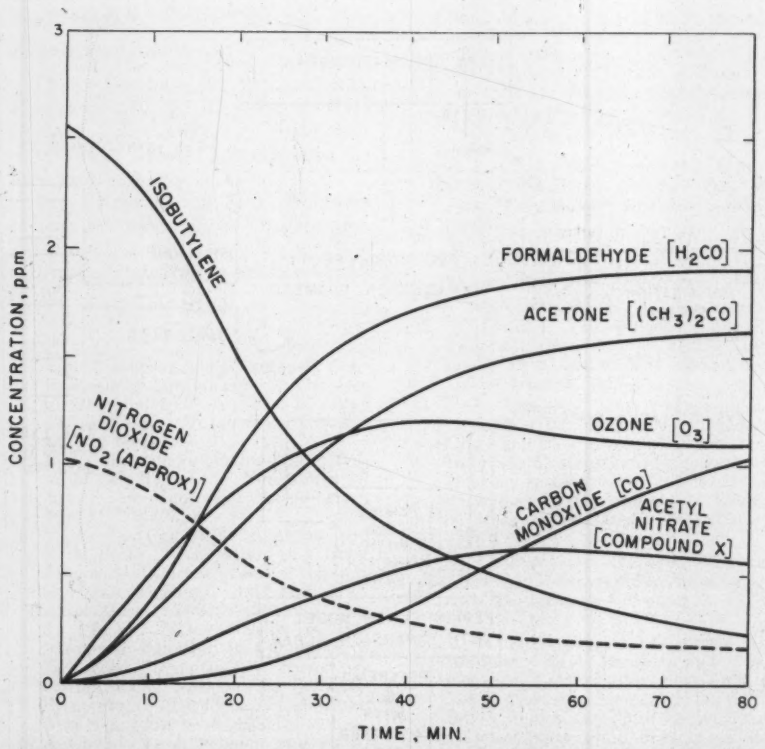

Fig. 4. Time concentration curves for reactants and products during irradiation of isobutylene and nitrogen dioxide.

Results and Discussion

Products

Products obtained from typical photooxidations are shown in Table I. The olefinic hydrocarbons studied yielded substantial amounts of products at the end of 2-hr of irradiation. The saturates were relatively unreactive and yielded small amounts of products. Those mixtures which yielded little or no products did not give eye irritation. Thus, we associated the irritation with products.

Eye Irritation Potential of Products

The test subjects were exposed to mixtures of known concentrations of individual compounds to determine the eye irritation potentials of several of the minor as well as the major products. These data are shown in Table II. Of the compounds tested, only formaldehyde and acrolein resulted in substantial irritation. These compounds are consistently identified as major products of the reactions and therefore probably contribute substantially to eye irritation. The epoxides probably do not contribute to eye irritation since they do not cause significant irritation even at concentrations 40 to 60 times greater than those found in the reacted mixtures. For similar reasons acetaldehyde, propionaldehyde, ketene, ethyl nitrate, and acetyl nitrate probably do not contribute to eye irritation.

Correlation of Eye Irritation with Certain Products

The formaldehyde and acrolein concentrations could be measured directly in many cases. In some experiments other aldehydes interfered with the formaldehyde absorption at 3.6 μ. In these cases the formaldehyde was determined by one or more of the following methods:

1. Measuring the interfering aldehyde at some other wavelength or by gas chromatography and applying a correction to the absorption at 3.6 μ.
2. Using differential infrared techniques.
3. Assigning an upper limit to the formaldehyde concentration on the basis of the 3.6-μ absorption.

Once the formaldehyde and acrolein concentrations were determined, it was possible to use the data from Table II (that is, 1 ppm of formaldehyde = 4.1 eye irritation units and 1 ppm of acrolein = 10.1 eye irritation units*) to calculate the irritation value to be expected for each experiment and to compare this calculated value with the observed

* Assumes a linear relationship between concentration and irritation.

Table I—Products Resulting from Photo-oxidation of Hydrocarbons with Oxides of Nitrogen[a]

(For certain products resulting from photo-oxidation of selected hydrocarbons with oxides of nitrogen)

Experiment Number	Hydrocarbon	Identified Products,[b,c] ppm: Formaldehyde	Carbon Monoxide	Acyl[d] Nitrates	Acetaldehyde	Acrolein	Acetone	Ozone
8	Propylene	1.20	0	0.35	1.20	0	0	0.68
127	Isobutylene	2.05	0.70	0.45	0	0	1.80	1.00
15	1,3-butadiene	1.80	0.80	0.05	0	1.70	0	0.65
99	n-Pentane	0	0	0	0	0	0	0.18
151	2-Methylheptane	0	0.40	0.15	0	0	0	0.45
16	Isooctane 2,2,4-Trimethylpentane	0	0.30	0.05	0	0	0	0.26

[a] 3 ppm of hydrocarbon and 1 ppm of nitrogen dioxide.
[b] After 100 min of irradiation.
[c] 0 in table indicates that compound was not found or that its concentration was below detection limit of instrument, i.e., less than 0.1 ppm.
[d] Calculated as acetyl nitrate.

Table II—Observed Eye Irritation Values

Compound Tested: Name	Concentration, ppm	Eye Irritation Index, Arbitrary Units: Concentration Listed	Per ppm of Compound
Acrolein	1.5	15.2	10.1
Formaldehyde	4	16.2	4.1
Propionaldehyde	3	2.4[a]	[a]
Ethylene oxide	3	2.0[a]	[a]
Ethyl nitrate	3	2.2[a]	[a]
Acetyl nitrate	3	1.8[a]	[a]
Ketene	10	6.0[a]	[a]
Butylene oxides	3	1.6[a]	[a]
Acetylaldehyde	10	2.0[a]	[a]
Ozone	1.0	3.0[a]	[a]

[a] Indistinguishable from zero irritation.

irritation. The first set of data chosen for comparative purposes was obtained from a group of 20 experiments in which isobutylene was photo-oxidized in the presence of 1 ppm of nitrogen dioxide. The isobutylene concentration was varied from 1 to 12 ppm. The resulting series of observed irritations varied from no, or very light, irritation (index = 2–6) to severe irritation (index = 16 or greater).† Among the products of this reaction, formaldehyde was the only irritant identified. Therefore, calculated irritation values were obtained from the measured formaldehyde concentration of each experiment. Both the observed and the calculated irritation values are listed in Table III. The correlation coefficient of these two values is 0.86. Statistically, 0.86 is indistinguishable from a correlation of 1.0; therefore, no attempt was made to correct for the known error of measurement associated with observed eye irritation.

Next, a comparative study was made of the irritation obtained by photo-oxidation of 1,3-butadiene in the presence of oxides of nitrogen. Among the products of this reaction were two identified irritants, formaldehyde and acrolein. Therefore, the calculated irritation was assumed to be the sum of the irritation resulting from these two products. The calculated irritation values of each of these irritants and the sum of these values are shown in Table IV along with the observed irritation levels. The correlation between the observed and the calculated values is greater than 0.86 and implies that all of the irritation has been contributed by formaldehyde and acrolein.

The above method of calculating eye irritation was next applied to data on various other olefins and compounds studied. A comparison of calculated and observed irritation values is given in Table V. Again, the correlation coefficient was found to be 0.86. Thus the observed irritation in all of the systems studied has been mainly contributed by formaldehyde and acrolein.

† On an arbitrary scale of 0–24.

Table III—Comparison Between Observed Eye Irritation and Eye Irritation Values

(Calculated From Photo-oxidation of Isobutylene with Nitrogen Dioxide)

Experiment Number	Observed Eye Irritation Index, Arbitrary Units	Calculated Eye Irritation Index, Arbitrary Units
126	4.4	2.0
211	4.7	2.4
124	6.0	6.0
106	3.6	5.2
128	10.4	6.5
123	8.4	7.2
110	5.2	6.8
104	6.8	7.6
114	9.6	8.8
113	9.5	8.8
132	8.8	8.4
137	9.2	9.6
130	17.2	11.2
116	16.5	13.6
109	12.4	8.0
118	12.5	8.4
125	12.9	10.4
119	12.8	13.2
135	11.3	12.0
133	19.2	14.0

Summary

Individual hydrocarbons were irradiated with near-ultraviolet light in the presence of nitrogen dioxide. Examination of the reacting systems with an infrared spectrophotometer and a gas chromatograph led to ready identification of major products.

Two products of the photo-oxidations, formaldehyde and acrolein, were found to be eye irritants and to account for the majority of the observed eye irritation found in the photo-oxidized systems studied. At the concentrations present in the photo-oxidized mixtures, epoxides, most aldehydes, ketones, nitrites, ketene, ozone, alkyl nitrates, and acyl

Table IV—Comparison Between Observed Eye Irritation and Eye Irritation Values

(Calculated From Formaldehyde and Acrolein Concentrations During Photo-oxidation of Butadiene with Oxides of Nitrogen)

Experiment Number	Calculated Eye Irritation Index (Arbitrary Units): From Formaldehyde	From Acrolein	From Formaldehyde and Acrolein	Observed Eye Irritation Index, Arbitrary Units
15	7.2	18.0	25.2	22.0
19	3.2	10.0	13.2	12.4
23	3.2	9.8	13.0	12.4
24	4.0	8.2	12.2	14.4
38	6.4	7.8	14.2	11.6
39	6.8	10.9	17.7	14.0

Table V—Comparison Between Observed Eye Irritation and Eye Irritation Values

(Calculated from Formaldehyde and Acrolein Concentrations During Photo-oxidation of Various Compounds)

Experiment Number	Compound	Calculated Eye Irritation Index, Arbitrary Units	Observed Eye Irritation Index, Arbitrary Units
7	Ethylene	2.8	2.4
30	Ethylene	8.8	8.8
90	Propylene	8.0	7.9
94	1-Butene	5.6	5.6
22	Trans-2-butene	4.0	7.6
75	2-Methyl-2-butene	6.0	4.0
31	2,3-Dimethyl-2-butene	4.4	7.6
102	1-Pentene	10.8	14.8
46	2-Ethyl-1-butene	6.8	8.8
82	3-Heptene	9.2	7.6
12	Cyclohexene	6.0	8.0
11	Diisobutylene (2,4,4-Trimethyl-2-pentene)	8.0	10.8
56	1,2-Butadiene	3.6	2.4
29	1,3-Pentadiene	17.8	16.4
18	2-Methyl-1,3-butadiene	19.9	16.8
34	2,3-Dimethyl-1,3-butadiene	8.8	12.8
55	1,5-Hexadiene	10.4	10.8
81	1,5-Cyclo-octadiene	4.8	10.8
98	Isopentane	0.8	3.2
99	n-Pentane	0.8	2.8
100	3-Methylpentane	0.8	2.4
101	Methane	2.0	3.2
16	Iso-octane (2,2,4-Trimethylpentane)	0.8	3.6
51	Cyclohexane	0.8	2.0
28	Methylethyl ketone	0.0	1.6
32	Stoddard solvent	0.0	6.3
35	Trichloroethylene	0.0	3.2
47	Tetrachloroethylene	0.0	2.8
43	Xylene	0.8	5.2
49	Xylene	6.4	5.6

nitrates were not eye irritants. Terminal olefins in general led to the greatest amounts of irritation. Internal olefins were of lesser importance in the formation of eye irritants in spite of their rapid rates of reaction. Saturates did not contribute to eye irritation because of their slow rates of reaction.

★ ★ ★ Section Hi-Lites ★ ★ ★

The West Coast Section of the Air Pollution Control Association held two well-attended dinner meetings during July.

On July 21, at Berkeley, Calif., 149 members and guests heard a panel discussion of the Bay Area Control District's new Regulation No. 2. The moderator, John Le Gros of Shell Chemical Corporation, described the regulation as dealing principally with the control of visible emissions, particulate matter, sulfur dioxide, and certain organics from industrial operations. He described the classification of operations covered by the regulation as incineration and salvage operations, heat transfer operations, general combustion operations, and a catch-all category called "general operations."

Paul Arnold, resident manager of U. S. Paper and Foundry Co., discussed the impact of the regulation on foundry operations. He called Regulation 2 a "tough but fair" law. Problems foreseen by the foundry industry include the difficulty of measuring "equivalent opacity of effluents," the problem of gas cooling if baghouses were required, the high cost of modifying existing plants, the maintenance of a competitive position (in some cases, even with East Coast plants), the high cost of control equipment 4% to 40% of plant investment, depending on the size of the foundry), the need for expert assistance to develop the cheapest method of compliance, and the problem of disposal air contaminants.

Carl Willenburg, production manager, Folger Coffee Company, spoke for the coffee roasting industry, which, he said, had been an integral part of the San Francisco economy since "the early days." Two million bags of green coffee came through the port of San Francisco in 1959. The two dozen coffee roasters in the area vary in size from those with one or two batch roasters (handling 500 pound batches) to those with continuous roasters handling up to 50,000 pounds per hour. Roaster temperatures reach 400° to 500°F. Both single-pass and recirculating types are used.

(Continued on p. 415)

LA MEAT PACKERS APPEAL TO BOARD

Los Angeles County meat packers appealed to the Board of Supervisors for an easing of Air Pollution Control District regulation of odor emissions from the processing of dead animals.

Representatives of Meat Packers, Incorporated, a trade association, told the supervisors that compliance with Rule 64, which was enacted in 1959 to reduce the stench from fertilizer and meat packing plants, and fish canneries, is proving costly to the industry.

Of the several types of control available, the lowest-priced were already in operation or have been installed by many packers, association spokesmen said, but this method now has been found to have increased water consumption by more than 100% and also has overloaded the Vernon sewers.

Air Pollution Control Officer Smith Griswold pointed out that the APCD had originally made it clear to the packers, when they applied for permits to install controls, that their choice of the cheaper type control device, while it would control odors, would also result in excessive use of water and cause sewage problems. The packers were cautioned to check with other governmental jurisdictions, such as the Sanitation District, before making such installations.

"To our knowledge none of the complaining firms obtained the necessary clearance from the Sanitation District before making these plumbing alterations," Smith Griswold, APC officer, said. "Had they checked this out they would not have to make changes."

A supporting report by APCD Director of Engineering Robert L. Chass showed that a satisfactory odor control installation could be made or modified at a typical plant for about $10,000. The type of installation would do away with both water and sewer problems.

Senator Chevez, in a report from the Commission on Public Works on June 24, 1960, recommended that Senate Bill S3108, which has an identical companion bill introduced into the House of Representatives simultaneously—HR-10696). be passed. The principal recommendations of Senator Chevez' committee would call for removing the time limitations and ceiling on the authorization for annual appropriation and delete the requirement that funds be allotted in accordance with regulations prescribed by the Secretary of HEW. The proposed amendment would provide for public hearings on air pollution problems by the Surgeon General which may be of broad significance or are interstate in character.

The DEVELOPMENT of Motor Vehicle EXHAUST EMISSION STANDARDS in California*

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Motor vehicle exhaust emissions are one of the most important causes of air pollution in California. Emissions from motor vehicles contribute a large part of the organics, carbon monoxide, and oxides of nitrogen in the atmosphere of the State's metropolitan regions. The need to control motor vehicle exhausts was first indicated in 1950 when it was demonstrated that organics and oxides of nitrogen were important factors in "photochemical smog.[1]" Since that time the significance of vehicle exhaust in the State's air pollution problem has been even more firmly established. In the Los Angeles area motor vehicle operation, and the provision of fuel for it, presently contributes more than 80% of the total hydrocarbon emissions, about 90% of the carbon monoxide and well over half of the oxides of nitrogen.[2]

Motor vehicles constitute an air pollution factor common to all of the densely populated areas of California. This is somewhat in contrast to the varying pattern of industrial and domestic sources that are found in the different localities. Furthermore, motor vehicles move freely across boundaries of local jurisdictions and are taxed and licensed by the State. As a result, it has been recognized that the State level of government has a responsibility in the control of these moving sources of air pollution. The extent of motor vehicle use and gasoline consumption in California is indicated in Fig. 1. Approximately 80% of the vehicles in California in 1958 were registered in counties that have experienced "photochemical smog." Half of these or about 40% of the State's total are registered in Los Angeles County.

While acknowledging a responsibility for controlling vehicle emissions, the State administration expressed the view that control legislation should be preceded by the adoption of standards of community air quality and motor vehicle exhaust emissions. These standards would provide a legal base for the enactment of control legislation. Accordingly, the Legislature passed Assembly Bill No. 1368 and Senate Bill No. 117 requiring the State Department of Public Health to develop and publish before February 1, 1960, standards for the quality of air and standards for the emission of exhaust contaminants from motor vehicles. Senate Bill No. 117 states: "It shall be the duty of the State Director of Public Health to determine by February 1, 1960, the maximum allowable standards of emissions of exhaust contaminants from motor vehicles which are compatible with the preservation of the public health, including the prevention of irritation to the senses."

Basis for Exhaust Standards

Several fundamental decisions had to be made before the standards for motor vehicle exhaust emissions could be developed. It was decided that a single standard would be adopted and that this standard would be aimed at achieving acceptable air quality in that area of the State with the most serious air pollution problem.

The term "exhaust contaminant" was taken to mean those gases emitted from the vehicle tail pipe. The questions of practical attainability and cost were not considered in determining the reduction in emissions that would be required to meet the air quality standards. The year 1970 was used as the target date in calculating the standards since a number of years would be required for implementation of controls for the exhaust emissions.

The import of these decisions was that the standard was to be aimed toward the achievement of an acceptable level of air quality in the County of Los Angeles, the area which has the most severe air pollution problem in the State. The application of the standard in other areas of the State would then be expected to provide some margin of safety in preventing air quality from deteriorating to the levels specified in the air quality standards.

In principle, the calculation of allowable vehicle exhaust emissions is straightforward and includes the following elements:

1. Evaluation of the current levels of air quality experienced on days of meteorological conditions unfavorable to the dispersal of pollutants.
2. Determination of the total vehicle exhaust emissions and the average concentration of pollutants in vehicle exhaust.
3. Determination of the total emissions of air pollutants from all sources.
4. Extrapolation of the emissions data to 1970.
5. Description of the quantitative relationships between air pollution effects and atmospheric pollutant concentrations.
6. Calculation of the necessary reduction in pollutant emissions to maintain the desired air quality on days of meteorological conditions unfavorable to pollutant dispersal.
7. Application of these reduction factors to the average exhaust contaminant concentrations.

In practice, the calculation was complicated by several factors. Uncertainties exist in the measurement of motor vehicle emissions as well as of pollutants from other sources. The state of knowledge is still rudimentary regarding the quantitative relationships between photochemical smog effects and the concentrations of the primary smog-producing pollutants. Nevertheless

* Presented at the 53rd Annual Meeting of APCA, May 22–26, 1960, Netherland-Hilton Hotel, Cincinnati, Ohio.

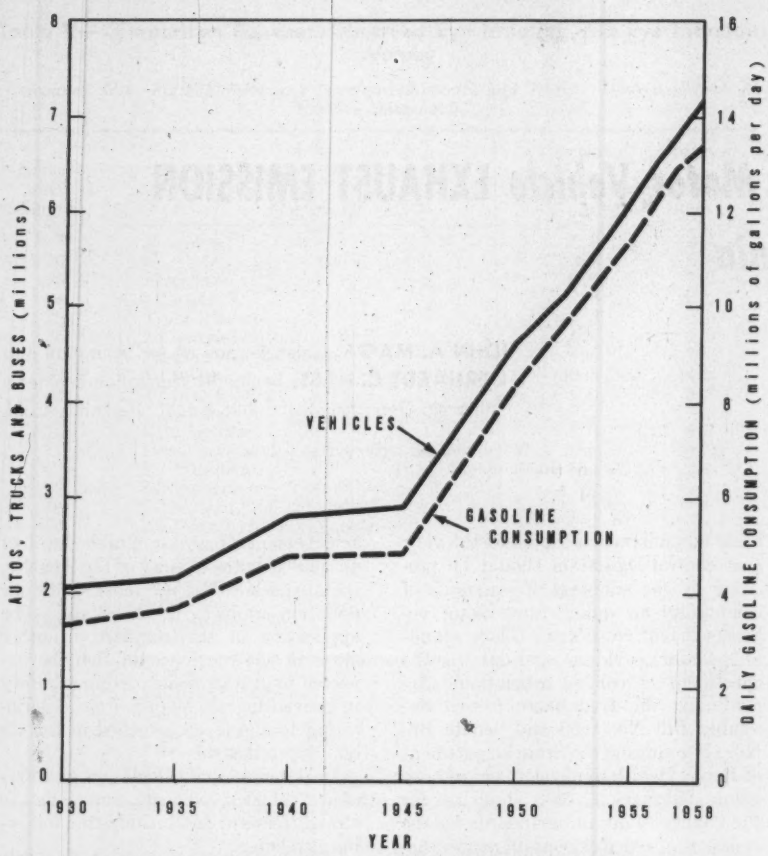

Fig. 1. Motor vehicles and daily gasoline consumption (California, 1930–1958).

the urgency of California's air pollution problem required action on the basis on what is presently known. The law provided for periodic revision of the standards when new information becomes available.

The air quality standards which were adopted by the California State Department of Public Health and which described the goal of the vehicle exhaust standards were:

"Oxidant Index"—0.15 ppm for 1 hr (average value as determined by the potassium iodide method).
Carbon Monoxide—30 ppm for 8 hr, or 120 ppm for 1 hr.

The most complicated case was imposed by the "oxidant index" standard. Oxidant is used as an indirect measure of eye irritation, plant damage, and photochemical aerosol formation. The value, 0.15 ppm, was chosen on the basis of its demonstrated association with these effects. It was not intended to impose a standard for ozone and nitrogen dioxide, even though these substances comprise a large part of the materials measured as oxidant by the potassium iodide method. Instead, oxidant was simply regarded as an empirical measure of the three sensible smog effects. It is probable that exhaust controls will alter the present association between oxidant and the other air pollution effects.

Air quality standards for ozone and nitrogen dioxide were considered independently by the Department. Standards for these two compounds were not adopted because of the lack of sufficient data. However, the numbers which were considered, and which are included in footnotes to the air quality standards, were higher than those which have been recorded in Los Angeles County.

The "oxidant index" standard refers to substances which do not appear in vehicle exhaust, but which have their origin in the action of sunlight on materials emitted from motor vehicles as well as other sources. The quantitative relationships between these photochemical products and the concentrations of the primary pollutants, therefore, had to be considered.

Many investigators have established that both organic compounds and nitrogen oxides are necessary to the photochemical production of ozone, eye irritant, "typical oxidant" phytotoxicant, and photochemical aerosol. The variation of these effects as functions of varying concentrations of organics and nitrogen oxides is less clear. The importance of organic compound type (i.e., olefins, paraffins, aromatics, and chain length) on the development of the several end effects has not been completely established.

Following a review of the literature and consultation with scientists who have studied the reactions, the following relationships were postulated for the purpose of developing standards:

1 The maximum concentration of ozone which can be developed in a polluted atmosphere is proportional to both the concentration of organics* and nitrogen oxides.
2 The maximum concentrations of eye irritant, "typical oxidant" phytotoxicants, and photochemical aerosol which can be developed in a polluted atmosphere are proportional to the concentration of olefins. Nitrogen oxides are considered to be necessary to the reactions, but are not considered to be linearly effective as in ozone formation.

An underlying assumption, of course, was that these relationships are restricted to solar radiation and contaminant concentrations comparable to those obtained in California cities.

It is obvious that these relationships cannot be considered to be a complete and accurate statement of the photochemical smog reactions. For example, it is known that within the olefinic class of organic compounds there are important differences in reactivity of compounds depending on chain length, number and position of double bonds, chain branching, and the presence of other functional groups. It would be desirable to assign a significance factor to each compound which takes part in the photochemical reactions. Present data, however, do not permit such discrimination. It was decided to distinguish between only two classes of reactivity, i.e., olefins and nonolefins. Ethylene was included with the other olefins in our calculations.

Upon consideration of the postulated smog reactions, the objective of the "oxidant index" standard can be interpreted to require the reduction of atmospheric olefin concentrations to the levels currently associated with 0.15 ppm oxidant.

Because data on motor vehicle emissions are not generally in terms of olefins, and there are no suitable field survey techniques for measurement of total olefins in exhaust, it was decided to use exhaust hydrocarbons (as measured by a hexane-sensitized nondispersive infrared analyzer) as the exhaust component expressed in the standards. At present the infrared analyzer is commonly used to measure exhaust hydrocarbons and most of the data on hydrocarbons is in terms of this method. This assumed that a given reduction in ex-

* Methane excluded.

haust hydrocarbons would accomplish a commensurate reduction in exhaust olefins.

The carbon monoxide standard presented a much simpler problem. Air quality standards were specific for this compound and did not rely on empirical measurements or a demonstrated association with another measurement. In the air quality standards carbon monoxide was considered a pollutant because of its interference with the oxygen transport of blood and not because it was a factor in photochemical reactions.

Hydrocarbon Standard

Two methods were used to determine the amount of exhaust hydrocarbon control required. The first, which has been called the "rollback" method, is based on the premise that the total Los Angeles emissions in the year 1940 resulted in smog effects approximately equivalent to the 0.15 ppm oxidant level on days of very limited atmospheric dispersal. Accordingly, inventories were constructed of all sources of olefins in the years 1940 and 1970. These are shown in Table I.

The required exhaust olefin removal is dependent on the extent to which nonexhaust olefin emissions are controlled. Under rules adopted by the Los Angeles County Air Pollution Control District, substantial reductions in hydrocarbons, including olefins, have been accomplished by the control of petroleum refining and storage losses since 1940. As a result of the control program of that District, the 1970 estimated olefin emissions from nonexhaust sources are expected to be maintained at approximately their 1940 level. The calculation for the motor vehicle exhaust emissions, therefore, reduced to determining the degree of control required to reduce exhaust olefin emissions from the 1970 to the 1940 level. It was determined that the 1970 exhaust olefin emissions should be reduced by a factor of about 0.77.

The second method of estimating the amount of reduction needed has been called the "indicator contaminant method." This approach used carbon monoxide concentrations in the atmosphere as a measure of its relative dilution capacity. Carbon monoxide was especially suited to this purpose because it originated primarily from motor vehicle exhaust, could be reliably measured, and was a relatively stable compound. A comparison of the concentration of carbon monoxide on a severe smog day to the concentration found on a day of 0.15 ppm oxidant was considered to define the reduction in olefin emissions required to improve the air quality on a severe smog day to an acceptable level. A severe smog day was defined for this purpose by the 99th percentile oxidant value for all the days of record. This, of course, assumes that there is a reasonably constant ratio between carbon monoxide emissions and the emission of olefins, the exhaust component of interest.

A study was undertaken by the U. S. Public Health Service at the request of this Department to investigate the relationship between carbon monoxide and oxidant measurements at two stations in Los Angeles County. Morning concentrations of carbon monoxide between the hours from 6 AM to 12 noon for the years 1956 and 1957 were compared with the maximum hourly oxidant developed for the corresponding day and station. Correlation and regression analyses were obtained by computer for various groupings of the data by season, day of week, and by solar radiation intensities. As expected, the correlation was found to be erratic for the winter months and on days of low solar radiation. A good correlation was obtained for the station in downtown Los Angeles when the comparison was restricted to weekdays of high solar radiation intensity. The corresponding arithmetic and geometric regression lines indicated an approximately linear relationship between carbon monoxide and oxidant under these conditions.

This approach indicated that olefins needed to be reduced by a factor of 0.68 in 1957. Extrapolation of emissions to 1970 indicated that an 81% reduction in olefin emissions was needed.

As a result of these two approaches for calculating the exhaust control required, 0.80 was used as the reduction factor to be applied to the current average exhaust olefin emissions.

The measurement of the average concentration of hydrocarbons in the exhaust streams of a representative sample of motor vehicles is a very difficult problem. Analytical methods for hydrocarbons have never been considered to be entirely satisfactory. The various studies on emissions from motor vehicles have been reported in terms of differing driving cycles and differing sampling instruments and techniques, making comparison of results uncertain. It was concluded that the Comprehensive Exhaust Gas Field Survey conducted by the Co-ordinating Research Council in Los Angeles in the fall of 1956 used the most appropriate methods for selecting a representative sample of automobiles and testing them under a controlled operating cycle.[3] This study showed an average hydrocarbon loss of 5.9% by weight of the supplied fuel. (Hydrocarbons measured by hexane-sensitized infrared analyzer.) Consideration of the other studies leads to the conclusion that the Field Survey results are probably too high. The judgment was made to assume a 5% weight loss of the supplied fuel for the purpose of calculating the standards. This corresponds to a concentration of 1375 ppm hydrocarbons as hexane in a composite sample representative of the driving pattern used in the Co-ordinating Research Council study. There is reason to believe that this figure may still be higher than the true value. New studies are in progress to establish the present average concentration on a sounder basis.

The hydrocarbon standard was then calculated by combining the reduction factor and the estimated current average hydrocarbon concentration in vehicle exhaust as follows: (1 − 0.80) 1375 = 275 ppm as hexane.

Table I—Estimated Olefin Emissions Los Angeles County

Los Angeles County (tons per day)

	1940	1970
Total	206	657
Vehicular emissions		
Exhaust losses	134	596
Gasoline tank losses	6	13
Carburetor operating losses	7	16
Carburetor hot soak losses	2	5
Petroleum refining and storage	45	13
Petroleum marketing		
Transport Loading	7	1
Filling Service Station and Vehicle Tanks	5	13

[a] Data taken from "Technical Report on Ambient Air Quality and Motor Vehicle Exhaust Standards," California Department of Public Health.

Carbon Monoxide Standard

The exhaust standard for carbon monoxide was arrived at by examining the air monitoring records of the Los Angeles County Air Pollution Control District and calculating the reduction in carbon monoxide emission needed to prevent the occurrence of 8-hr episodes of 30 ppm or more. There were no cases when carbon monoxide reached 120 ppm for 1 hr. It was found that a 33% reduction was required for the year 1957. Extrapolation to the year 1970 led to the conclusion that a 60% reduction was necessary. It was estimated that motor vehicles would be the only significant source of carbon monoxide in 1970 (see

Table II—Estimated Carbon Monoxide Emissions[a]

Los Angeles County (tons per day)

	1957	1970
Total	8600	12,700
Vehicular exhausts	7200	12,100
Petroleum refining	1200	300
Metals manufacture	200	300
Other sources	<10	<10

[a] Data taken from "Technical Report on Ambient Air Quality and Motor Vehicle Exhaust Standards," California Department of Public Health.

Table III—Standards for Motor Vehicle Exhaust Emissions

The standards of emissions of motor vehicle exhaust contaminants are:[a]
Hydrocarbons—275 ppm by volume as hexane. (0.165 mole percent carbon atoms.)
Carbon monoxide—1.5% by volume.

The standards refer to a composite sample representing the driving cycle described below. Exhaust gas concentrations shall be adjusted to a dry exhaust volume containing 15% by volume of carbon dioxide plus carbon monoxide.

Hydrocarbons are defined as the organic constituents of vehicle exhausts as measured by a hexane-sensitized nondispersive infrared analyzer or by an equivalent method.

Carbon monoxide shall be measured by a nondispersive infrared analyzer or by an equivalent method.

Driving Cycle

Condition	Rate of Speed Change, mph/sec	Percent of Total Time	Percent of Total Sample Volume
Idle	—	15.0	4.2
Cruise, mph			
20	—	6.9	5.0
30	—	5.7	6.1
40	—	2.7	4.2
50	—	0.7	1.5
Acceleration, mph			
0–60	3.0	1.1	5.9
0–25	2.2	10.6	18.5
15–30	1.2	25.0	45.5
Deceleration, mph			
50–20	1.2	10.2	2.9
30–15	1.4	11.8	3.3
30– 0	2.5	10.3	2.9
		100.0	100.0

[a] It has been judged that an over-all 80% reduction of motor vehicle exhaust hydrocarbon emissions is needed. The hydrocarbon concentration expressed in these standards was derived by applying this percent reduction to the current estimated average exhaust hydrocarbon concentration.

It has been judged that an over-all 60% reduction of motor vehicle exhaust carbon monoxide emissions is needed. The carbon monoxide concentration expressed in these standards was derived by applying this percent reduction to the current estimated average exhaust carbon monoxide concentration.

In the application of the standards to the approval of exhaust control systems, consideration must be given to such factors as warm-up time, reliability, and effective life of control devices, and exemption of certain groups of vehicles from compliance. If a substantial number of vehicles are allowed to greatly exceed the standards the objective of the standards may not be reached.

Table II). This is to a large extent due to the construction of carbon monoxide boilers at petroleum refineries in that area by 1970.

The estimated current average carbon monoxide concentration in exhaust was derived from the Co-ordinating Research Council Field Survey study previously cited. This value is 3.8% by volume for a composite sample representing the standard driving cycle. This is believed to be a more firm figure than the corresponding hydrocarbon value. Other studies are in reasonable agreement with this figure.[4]

The carbon monoxide standard thus becomes: $(1 - 0.60)\ 3.8 = 1.5\%$ by volume.

Standards Adopted

The standards as adopted by the California Board of Public Health on December 4, 1959, are shown in Table III. The reference driving cycle is included with the statement of the hydrocarbon and carbon monoxide concentration. The gas concentrations are qualified by requiring a correction to a 15% ($CO + CO_2$) concentration to protect against spurious results achieved by the addition of excess air to the exhaust stream.

Other Exhaust Pollutants

Standards were adopted for hydrocarbons and carbon monoxide, but not for other pollutants present in motor vehicle exhausts. Other substances in exhausts that have received considerable attention in California are lead, oxides of nitrogen, and sulfur dioxide.

The motor vehicle exhaust standard did not include lead because no air quality standards were adopted for this heavy metal. In considering the air quality standard, considerable attention was given to lead because atmospheric lead levels in Los Angeles are among the highest found in large American cities. It was finally concluded that information on atmospheric lead exposure of populations did not permit a standard at this time.

There were a number of reasons why a standard for oxides of nitrogen was not set for exhaust emissions. As has already been indicated, the air quality standards did not include oxides of nitrogen or ozone. It is generally considered that a large reduction in olefinic hydrocarbons alone, as required by the standards, will accomplish a marked improvement in "smog" conditions that lead to eye irritation, vegetation damage, and reduction of visibility. While nitrogen dioxide is an important component in the photochemical reaction, hydrocarbon control would be required in any event. Nonexhaust hydrocarbons have been controlled in Los Angeles, but such has not been the case for oxides of nitrogen. A control of oxides of nitrogen in exhaust at this time would still permit large quantities of these compounds to be emitted from other sources.

Should air quality standards be adopted for ozone or nitrogen oxides at or below levels measured in California communities, it is likely a motor vehicle exhaust standard for oxides of nitrogen would be indicated. Continued growth of metropolitan regions and increased use of motor vehicles also indicate the possibility that an oxide of nitrogen standard will be necessary.

Recent studies[5] have shown that sulfur dioxide in exhausts is significantly involved in the development of aerosols upon irradiation. The concentration of sulfur dioxide in exhaust is sufficiently low at present so that the current air quality standard for sulfur dioxide (0.3 ppm for 8 hr) is not exceeded in areas of high traffic density. However, the involvement of sulfur dioxide in photochemical aerosol formation requires careful study. It is conceivable that the limitation of motor fuel sulfur content may be needed in the future as an air pollution control measure.

Crankcase Emissions

At the time standards were being developed it was assumed that crankcase vent gases represented only a small percent of the exhaust hydrocarbons. This assumption was based on published studies[6] and available data on hydrocarbon losses from all sources. As a result, the exhaust standards did not take "blowby" into account. Since that time, information has been published that indicates "blowby" may contribute substantially to the total hydrocarbon emissions.[7] At the first revision of the standards, these crankcase emissions will also be taken into consideration. It is hoped that the contribution of "blowby" to total hydrocarbon losses will be more firmly established by that time.

Conclusion

The motor vehicle exhaust standards

(*Continued on p. 414*)

CONTROL *of* NITROGEN OXIDES *in* BOILER FLUE GASES *by* *Two-Stage Combustion**

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There are always small amounts of nitrogen oxides, principally nitric oxide, present in the combustion products discharged from boilers, industrial furnaces, automobile engines, and any other equipment that burns fuel at high temperatures. Haagen-Smit,[1,2] Stephens,[3] Johnston,[4] and others have shown that these oxides, when discharged into the atmosphere, react photochemically with hydrocarbons there to form smog. This is occurring to some extent in several of our large industrial cities, but is probably most severe in the Los Angeles basin. Although steam-power plants account for only 15 to 20% of the total nitric oxide produced,[5] in the interest of overall air pollution control it was deemed necessary to determine what could be done to bring this source under control.

Since early 1957, the Babcock and Wilcox Company has been conducting an investigation, in co-operation with the Southern California Edison Company, to determine what could be done to reduce the nitric oxide concentration in flue gases from power plants in the Los Angeles area burning residual oil and natural gas. The investigation developed into a three-phase program. The first phase dealt with a study of operating boilers to determine the levels of nitric oxide which existed in the flue gases, the effect of burner and furnace design upon the nitric oxide level, and whether the amount of nitric oxide in the flue gases could be reduced by making changes in operating procedures or minor alterations to burners. The second phase consisted of laboratory studies to isolate the important design and operating variables affecting the formation of nitric oxide during combustion. The third phase dealt with field tests to check the control method developed in the laboratory.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

The purpose of this paper is to present the results of the investigation which subsequently led to the application of a method for reducing nitric oxide emission from power plant stacks.

General Considerations

Nitrogen dioxide (NO_2) is considered to be the nitrogen compound that takes part in the complex reactions leading to smog formation. Thermodynamic considerations[6] point to the fact that nitric oxide (NO) would be the primary nitrogen oxide formed during combustion of a fuel with air, although other oxides might be present due to secondary reactions. The high temperatures attained in the flame promote the fixation of nitrogen in the combustion air according to the reaction $N_2 + O_2 = 2NO$. Chemical equilibria and reaction rates favor its further oxidation at lower temperatures according to the reaction $2NO + O_2 = 2NO_2$. It is reasonable to believe, therefore, that NO is the primary oxide of nitrogen formed in a boiler furnace, and that the amount of NO_2 present is at a minimum until the flue gases enter the atmosphere where lower temperatures and an abundance of oxygen enhance its formation.

In order to determine the total amount of nitrogen oxides formed during combustion, it is necessary to use an analytical method that measures the amount of nitric oxide and the small amounts of the other oxides of nitrogen that may be present in the flue gases. The phenoldisulfonic acid method,[7] which has been widely used in air pollution studies, was therefore chosen for use in the investigations described in this paper. Since the method does not distinguish between the individual oxides of nitrogen, and because of the reasons stated above, we have chosen to report the results of our flue gas analyses as total oxides expressed as nitric oxide.

Possible Approaches

Various approaches have been considered for reducing the nitric oxide content of flue gases. These include methods for the catalytic decomposition of the oxides already formed in the high temperature region of combustion flames, and methods for adsorption of the oxides on active surfaces. Many of these methods are technically feasible, but involve the use of additional equipment and chemical media that make them somewhat unattractive for power plant application.

Because of our Company's experience in furnace and burner design, it was believed that our best contribution could be made in the realm of boiler design or operation. Within this area, there were methods to be considered which might bring about an effective decrease in peak temperatures, hence reduce the initial amount of nitric oxide formed. Among these methods were the introduction of inert gas through the burner as suggested by T. S. Bacon,[8] the admission of exhaust steam for flame cooling, the use of increased excess air, and the addition of cold surface in the burner zone.

Another method considered was to reduce the intensity of combustion by decreasing the turbulence of the fuel-air mixture at the burner. This could be achieved by adjusting air registers, modifying atomization, or making other burner alterations.

Exploratory Work in the Field

The first approach tried was to investigate the possibility of reducing the amount of nitric oxide in the flue gases by making changes in operating procedures or minor alterations to burners. The unit selected for obtaining this information was a boiler at Southern California Edison's El Segundo Steam Station. A side-sectional view of the boiler is shown on Fig. 1. This unit is fired by 16 combination gas and oil burners and delivers 1,140,000 lb

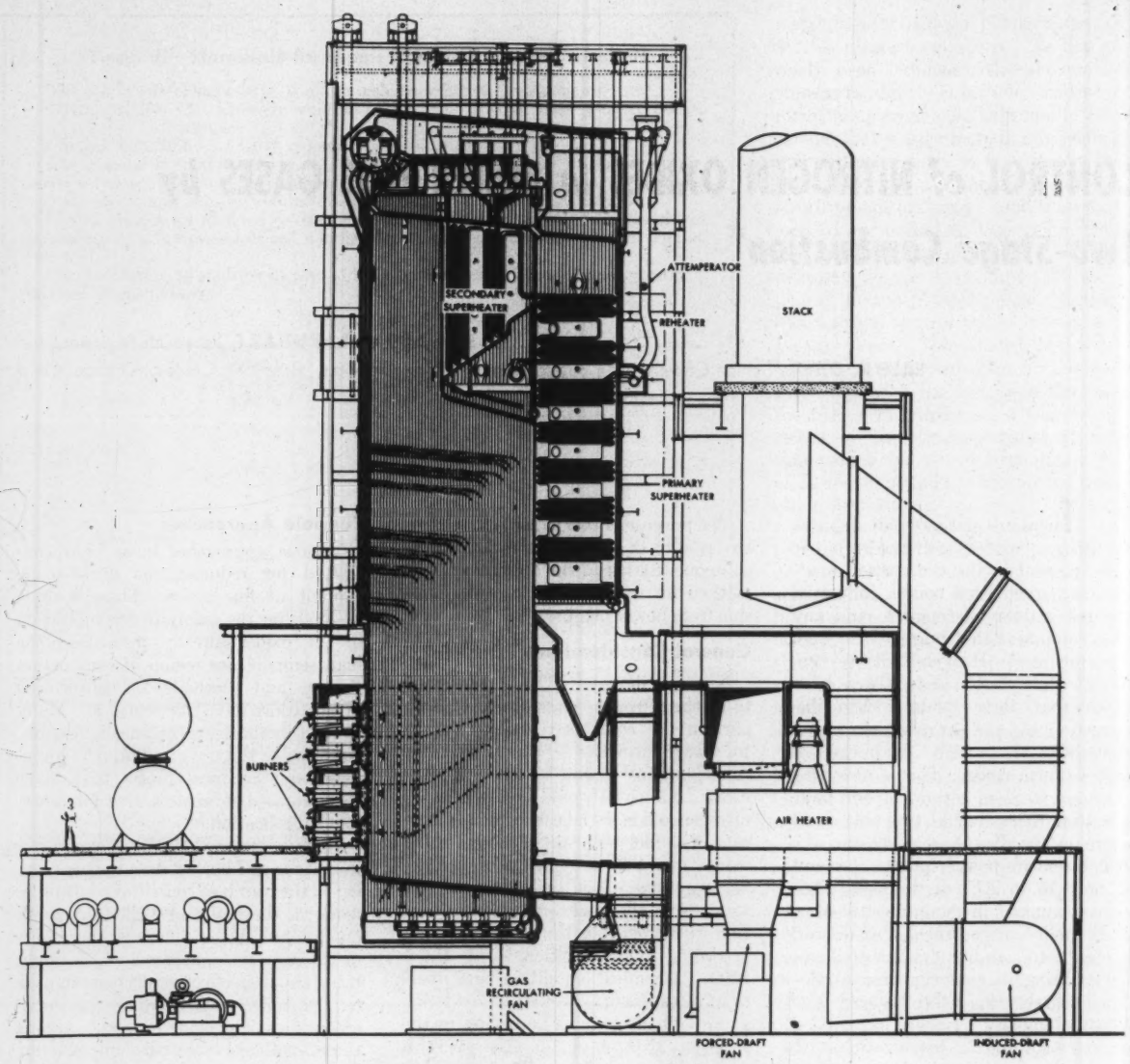

Fig. 1. Boiler No. 1, El Segundo Steam Station, Southern California Edison Co.

of steam per hour at 1860 psi and 1000°F. It employs attemperation and flue gas recirculation for steam temperature control and uses 600°F preheated air for combustion.

Previously, it had been established that the nitric oxide concentration in the flue gas from the boiler during full load oil firing was approximately 685 ppm.†

During the period from April 8 to July 10, 1957, a series of tests was performed to investigate the effect of certain operating variables on nitric oxide formation. Only those variables were tested that did not require extended boiler outages for changes in equipment, and did not interfere with the boiler's ability to meet its load demands.

† All nitric oxide concentrations referred to in this paper are reported as parts per million by volume (ppm), calculated to a base of 115% total air.

The results of these tests indicated that nitric oxide level decreased with a decrease in boiler load. At full load and a given burner setting, the nitric oxide concentration increased when the total air was increased from the normal 108% to a high of 132%. Gas recirculation through the lower rear wall had no noticeable effect on nitric oxide level.

In addition, it was found that any change made on the burner (a view of a combination oil and gas burner is shown on Fig. 2) that delayed mixing of the fuel and air resulted in a lower nitric oxide concentration in the flue gases. For example, while firing oil, removal of the approach-cone vanes from the burners and operation with air registers wide open (instead of the normal biased position) reduced the nitric oxide concentration in the flue gases from 685 ppm to 575 ppm, or about 16% (Fig. 3). Although furnace conditions were very good, the decrease in nitric oxide content was far less than that desired.

A 40% reduction in nitric oxide was obtained by moving the burner impeller all the way forward. However, long, smoky flames filled the furnace and frequently carried over into the superheater. Obviously, these conditions could not be tolerated in regular operation, and it was therefore decided that some other method of burning had to be found that would reduce nitric oxide formation and still burn all the combustibles well ahead of the superheater inlet.

Another part of the exploratory work in the field was to accumulate more information concerning the levels of nitric oxide in boilers of different design, as well as in those burning different fuels. To obtain this informa-

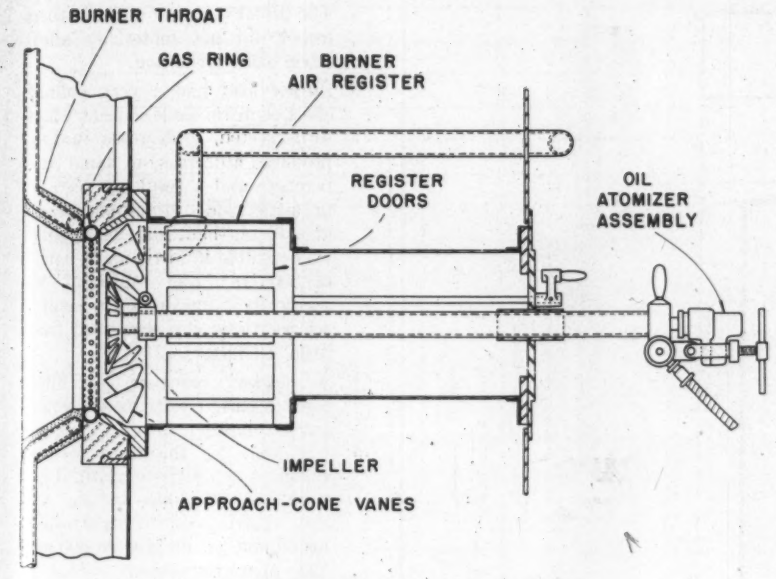

Fig. 2. B&W combination gas and oil burner.

tion, a survey was made of more than a dozen field units throughout the country.

Typical nitric oxide concentrations measured during this survey are shown on Fig. 4. These measurements were made with the boilers operating at full load. The levels shown for oil firing ranged from a low of 330 ppm to a high of 915 ppm; for gas, from a low of 160 ppm to a high of 1140 ppm. It is also interesting to note that for several coal-fired boilers tested, the nitric oxide concentration varied from a low of 650 ppm to a high of 1420 ppm.

The survey stressed the importance of considering all design factors (burner design, proximity of burners, flame pattern, degree of turbulence in the furnace, surface-to-volume relationship, etc.) in evaluating the differences observed among the various installations. Results of the field survey did not reveal any consistent relationship between fuel type and nitric oxide level.

Since it was possible that certain individual constituents in fuel, such as sulfur, nitrogen compounds, etc., might have some effect on nitric oxide formation, analyses were made of several samples of natural gas. These samples represented fuels burned in boilers which showed extreme differences in nitric oxide formation. The results of some typical analyses are shown in Table I.

The analyses revealed nothing which could explain these differences. For example, it was found that the concentration of combined nitrogen compounds in these samples was so low that it could account for less than 10 ppm nitric oxide in the flue gas. This is not considered a significant quantity in view of the large variation in nitric oxide concentration found in the boilers burning the gases analyzed.

The results obtained from similar analyses of several residual oils gave further evidence that differences in nitrogen content in the fuels were not responsible in any significant way for differences in the nitric oxide content of the flue gases.

As to the possibility that the sulfur content of the fuel might account for some of the differences in observed nitric oxide concentrations, no definite relationship could be developed from field data. It was decided, therefore, to make a test run in the laboratory where sulfur would be the only variable. A four-fold increase in the sulfur content of a residual oil showed no significant change in the level of nitric oxide formed.

As a result of the exploratory field work, it became apparent that additional study would be required in order to investigate fully the factors affecting nitric oxide formation during combustion. Since it was not feasible to continue this on field units, an experimental program was undertaken on one of the burner test units at the Babcock and Wilcox Company's Research Center in Alliance, Ohio.

Table I—Typical Fuel Gas Analyses

Station	El Segundo	C	D
Nitric oxide in flue gas, ppm	520	1030	410
Analysis of fuel gas			
Chemical analysis, ppm combined nitrogen	37	40	70
Mass spectrometric analysis, %			
Elemental nitrogen	1.60	2.20	2.00
Helium	0.00	0.00	0.00
Carbon dioxide	0.57	0.20	0.24
Methane	88.8	88.3	87.1
Ethane	6.9	7.3	8.5
Propane	1.8	1.9	2.0
N-butane	0.17	0.03	0.07
Isobutane	0.13	0.02	0.05
Pentanes	0.03	0.03	0.02
Hexanes	0.03	0.03	0.01
Heptanes	0.01	0.02	0.01
Gross heating value, btu/scf	1062	1061	1071
Specific gravity (air = 1)	0.624	0.623	0.629

Laboratory Investigations

Essentially, the test unit used in these investigations (Figs 5 and 6) is a water-cooled tunnel 12 ft in diameter and 22 ft long, designed to accommodate and test full-size burners. The unit is equipped with suitable controls and auxiliary equipment to provide maximum flexibility for studying design and operating variables.

Preliminary tests to establish base conditions showed that the nitric oxide concentration produced in the test unit was approximately 300 ppm. Although this was less than half the concentration found at El Segundo, there were several reasons why the difference existed. The furnace surface-to-volume ratio in the test unit is more than twice that existing in the ordinary commercial boiler. This has a marked effect on keeping the peak temperatures reached in the burner flame considerably lower than those reached on a field unit. Single burner operation on the test unit is another factor which probably reduces peak temperatures. The mutual support of multiple burners on a commercial boiler tends to reduce radiation of heat from the burner flame and elevates the maximum temperatures achieved in the burner zone. Our experience in extrapolating pilot data to full-scale performance, nevertheless, gave us confidence that trends observed on the test tunnel could be expected to occur in the field.

A systematic investigation on this unit brought out a number of important relationships concerning the effect that burner-furnace design and operating

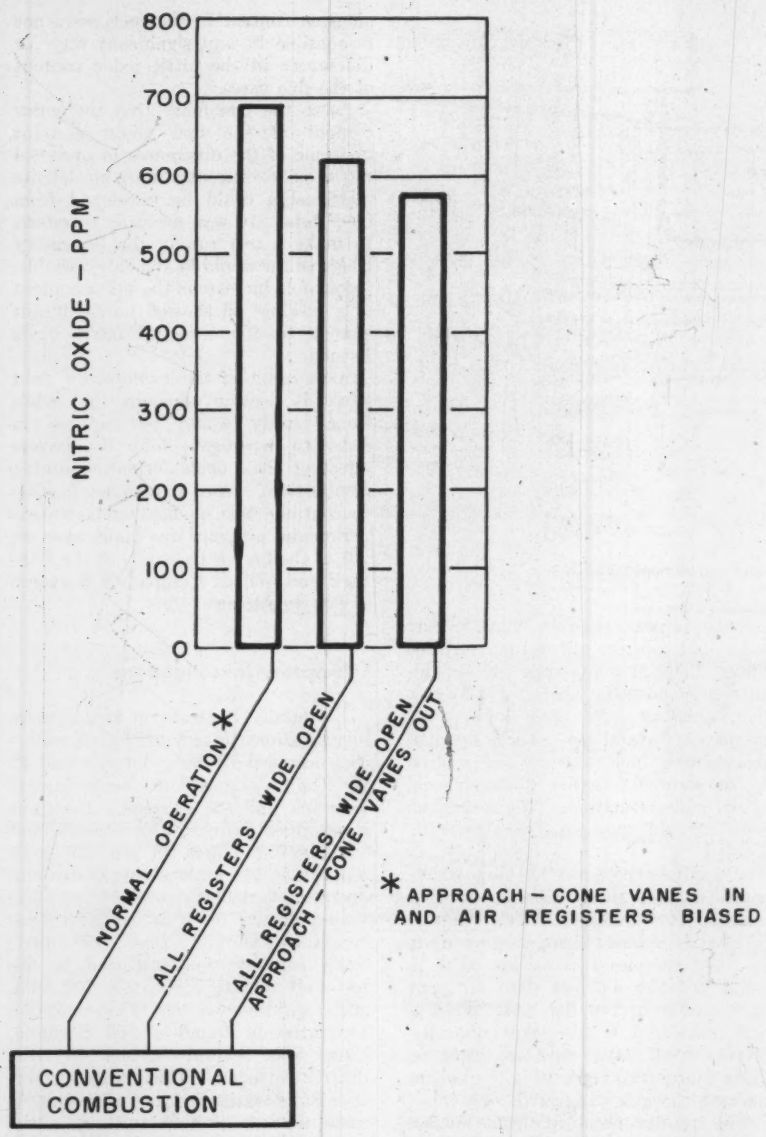

Fig. 3. Effect of burner alterations on nitric oxide concentrations, full load oil firing, El Segundo Steam Station.

variables have on the formation of nitric oxide during combustion. These relationships are shown on Figs 7 and 8 and may be stated as follows:

1. The position of the burner impeller did not have a great effect on the nitric oxide content of the flue gases until it was moved fully forward from its normal operating position. With the impeller in the forward position, the nitric oxide concentration was reduced to 155 ppm, a 48% reduction from the normal (300 ppm). This reduction compared favorably with the results obtained previously at El Segundo. Here again, we were not able to take advantage of this method of operating because of unsatisfactory flame conditions. Decreasing impeller diameter had an adverse effect on flame stability and resulted in unstable test conditions.
2. Removal of the approach-cone vanes resulted in a decrease in the nitric oxide level from 300 ppm to 285 ppm.
3. The use of various sprayer plates representing a range of atomization and spray-cone angle did not lower the nitric oxide concentration of the combustion gases, nor was there any significant difference between types of atomizers.
4. The throat diameter of the burners tested did not materially affect nitric oxide formation.
5. Burner load had a very definite effect on nitric oxide concentration. As expected, a decrease in load produced a decrease in flame temperature and a resulting decrease in nitric oxide formation. Tests at full, one-half, and one-quarter load resulted in nitric oxide values of 300, 185, and 145 ppm, respectively; maximum measured temperatures also decreased from 3165° to 3010° to 2110°F.
6. A marked reduction in nitric oxide occurred when propane was burned instead of oil. Propane was used for the tests because sufficient quantities of natural gas were not available at the test site. Nitric oxide concentrations for oil and gas firing were 300 and 124 ppm respectively. This is equivalent to a difference of 59%. A difference of 27% was obtained when comparing oil and gas firing on the El Segundo boiler. We believe that the greater difference on the test tunnel was due to the use of propane rather than natural gas.
7. A 460°F reduction in combustion-air temperature produced only a 50 ppm decrease in nitric oxide formation.
8. There was essentially no change in nitric oxide level when gas recirculation was simulated by introducing steam into the combustion air. This again compared favorably with the early tests at El Segundo. This test also served to demonstrate that reduction of flame temperature (some 200°F) by humidifying the combustion air had no effect on nitric oxide formation.
9. In the course of investigating the excess air variable, it was found that a substantial reduction of the nitric oxide concentration in the flue gases could be achieved by operating the burners with less than the normal amount of combustion air. The results of tests showed that once the total air through the burner was reduced to theoretical, further decreases produced substantial reductions in nitric oxide (Fig. 9). For example, with 95% of theoretical air through the burner, a 30% reduction was obtained; with 90%, the reduction was 55%. These results were obtained on both oil and gas firing.

For this method of operation to be applied effectively in a boiler, some way had to be found to introduce the re-

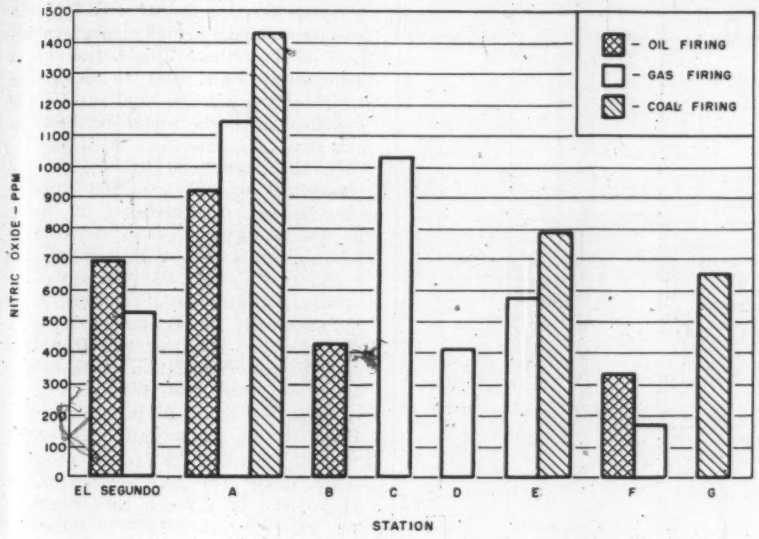

Fig. 4. Nitric oxide concentrations in various field units.

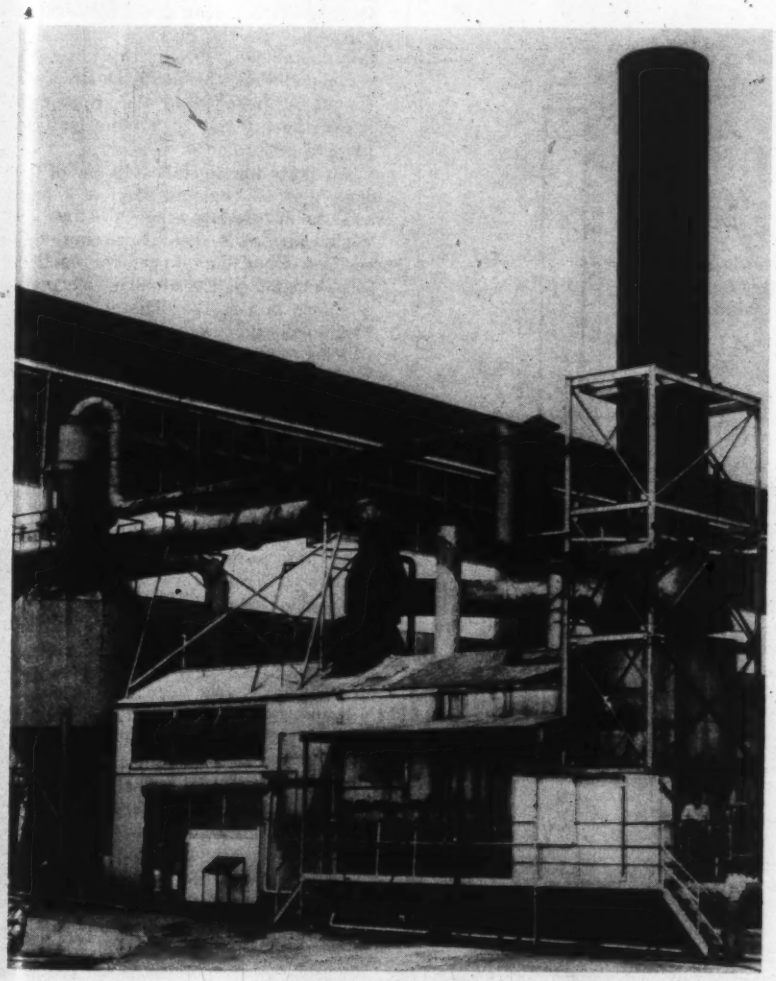

Fig. 5. Alliance test tunnel.

mainder of the air—"auxiliary air"—required to complete combustion. The next problem then was to determine the size, number, and location of auxiliary-air ports for several furnace designs.

This was accomplished, to a large extent, by a study of basic temperature and gas analysis data in the flame with various air-port combinations. It was found that practically all nitric oxide formation took place in a comparatively small high-temperature zone within a few feet of the burner. When auxiliary air was introduced so that it penetrated this zone, little or no reduction of nitric oxide level occurred. When, on the other hand, the auxiliary air was injected just beyond this zone, a maximum reduction of the nitric oxide level occurred, and although the flame was longer, combustion was still complete well within the furnace. When, however, the mixing of the auxiliary air and combustion gases was appreciably delayed beyond the zone of nitric oxide formation, combustion was not complete within the furnace. For best all around performance, therefore, the air ports must be properly located with respect to the burners.

The design of the air ports is equally important because this determines the rapidity of mixing of the auxiliary air and the combustion gases and the completeness of burn out in the second stage of combustion.

The problem of auxiliary-air port location and design on specific furnace designs was also studied on three-dimensional gas models[9] such as shown on Fig. 10. This is a $1/24$-scale model of a commercial unit that will employ this method of operation for controlling nitric oxide emission. Room temperature air was used to simulate auxiliary air, while air heated to 1000°F was used to simulate the combustion gases. At several locations on the model, velocity profiles can be measured to determine gas flow distribution, and temperature patterns can be measured to determine the degree or rapidity of mixing between auxiliary air and combustion gases.

The results of the model studies together with the information obtained during the tunnel tests permitted us to narrow down the large number of possible combinations of air-port locations to two or three which were then tested in the field.

Field Testing of Two-Stage Combustion

The introduction of a portion of the combustion air through the burners, and the remainder at some point beyond the burners, is the underlying principle of this method of reducing nitric oxide formation and has been termed "Two-Stage Combustion."

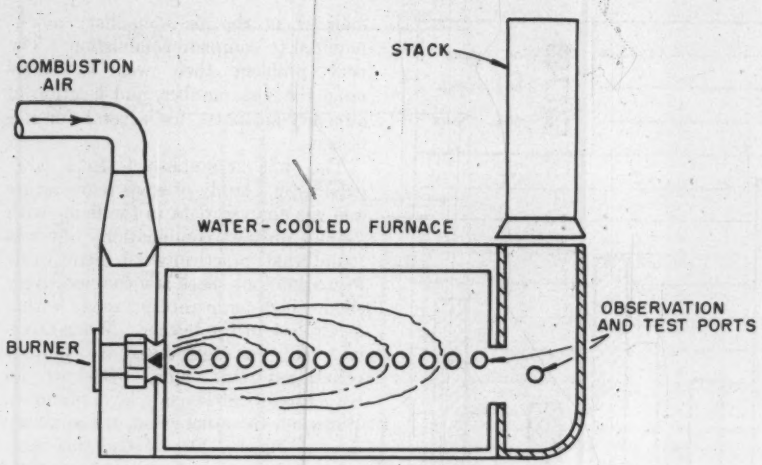

Fig. 6. Alliance test tunnel.

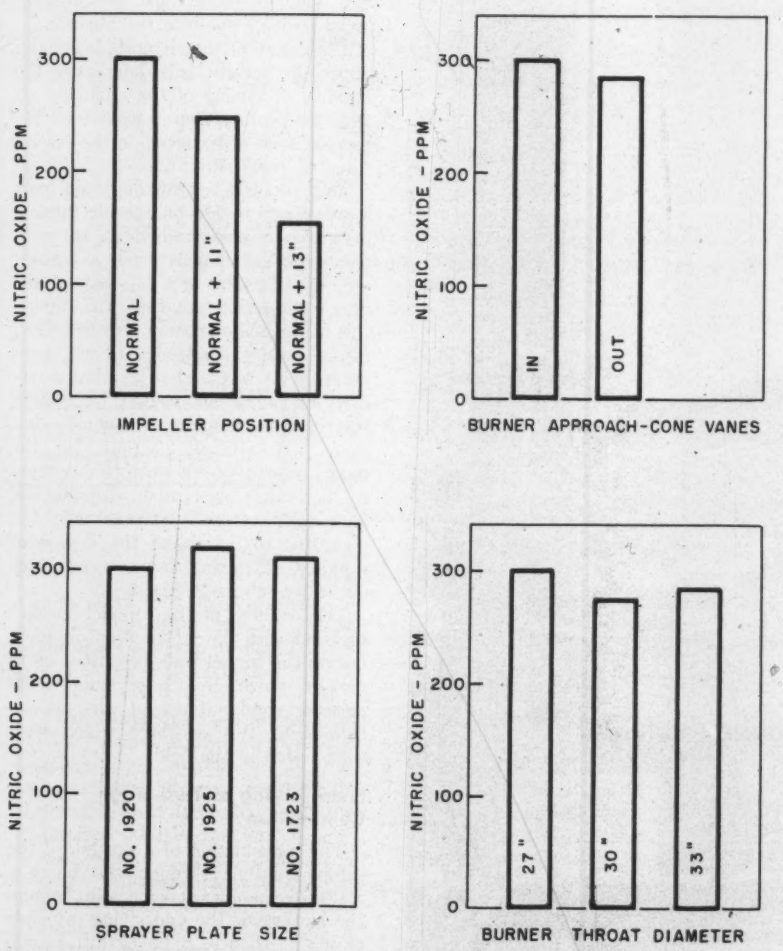

Fig. 7. Effect of burner design and operating variables on nitric oxide concentrations, Alliance Test Tunnel.

A second series of tests at El Segundo was run to make a preliminary evaluation of Two-Stage Combustion on a commercial scale, and to determine which of the possible locations for the auxiliary-air ports would be best on this type of furnace.

In these tests, 90 to 95% of the theoretical air was admitted through the burners. Furthermore, in order to take advantage of the decrease in nitric oxide level obtained during the exploratory work, the burners were operated without approach-cone vanes and with the air registers wide open. The auxiliary air was admitted first through gas-recirculation ports in the lower rear wall, then through various combinations of idle burners to simulate ports in the front wall, and finally through auxiliary-air ports installed in the upper rear wall of the furnace (Fig. 11). In general, the results of the tests confirmed those obtained at the Research Center, namely, that the nitric oxide level could be halved by utilizing Two-Stage Combustion with auxiliary-air admission through the front wall and that good combustion conditions in the furnace could still be maintained. From this, it was concluded that the auxiliary-air ports should be installed in the front wall above the top row of burners for best over-all performance.

Air ports were installed on one of the boilers at El Segundo so that a final evaluation of Two-Stage Combustion could be made before placing this method of burning into general practice. The location of the auxiliary-air ports is shown in Fig. 12. The objective of this evaluation was to measure and observe over-all performance of the boiler when Two-Stage Combustion was employed for the control of nitric oxide. Tests were designed to determine the effects of this method of burning upon flame conditions within the furnace, composition of the flue gases at various locations in the boiler, steam temperature control range, and heat absorption in the lower furnace, superheater, and reheater.

A set of tests was first run with conventional combustion, that is, with all of the combustion air through the burners. Then another set was run with 90 to 95% of theoretical air through the burners and the remaining 15 to 20% through the auxiliary-air ports. As in the previous tests, burners were operated without approach-cone vanes and with air registers wide open.

Traverses were made to obtain the temperature and the analysis (including combustibles) of the flue gases at the furnace and boiler outlets (Fig. 12). Gas samples for nitric oxide and combustibles were obtained at the air-heater inlet. Heat absorption data

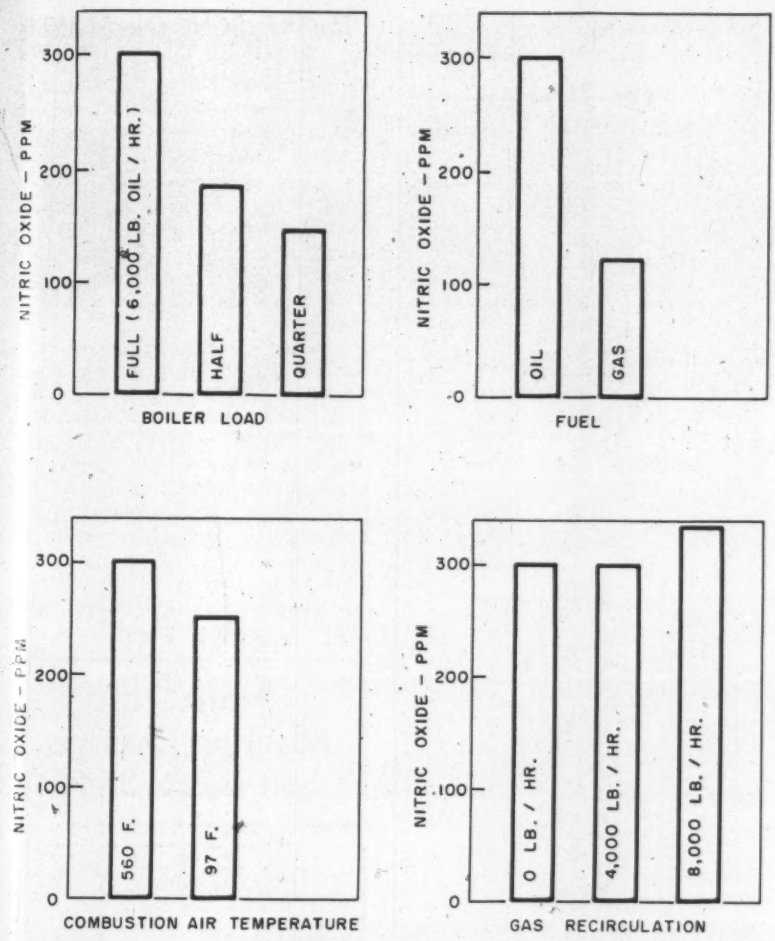

Fig. 8. Effect of burner design and operating variable on nitric oxide concentrations, Alliance Test Tunnel.

were taken in the lower furnace area, and motion pictures of furnace conditions were obtained during each test.

Judged by direct observation, gas temperature measurements, and motion pictures, general furnace conditions were completely acceptable. For the most part, the flames were confined to the furnace, and there was no evidence of carbon or gaseous combustibles at the furnace outlet. The color and density of the stack discharge appeared to be the same for normal operation and Two-Stage Combustion.

Two-Stage Combustion had no effect on steam temperature control range and furnace heat absorption during gas firing. It did have a slight effect on these quantities during oil firing. This, however, was not sufficient to affect station efficiency or over-all boiler performance.

While operating with Two-Stage Combustion, no difficulties were encountered when the boiler was automatically cycled from full to half to full load at the normal rate of load change on the turbine-generator.

With 95% of theoretical air through the burners, the nitric oxide concentration for both gas and oil firing was reduced from 525 ppm to 385 ppm. This represents a 27% reduction due to Two-Stage Combustion.

On oil firing, with 90% of theoretical air through the burners, the nitric oxide concentration was reduced from 580 ppm to 305 ppm, equivalent to a reduction of 47%. Unfortunately, it was not possible to obtain a comparable test on gas firing during the series at El Segundo. However, the trends shown on the Alliance test tunnel would lead us to expect an equivalent reduction (Fig. 13). The El Segundo results, it will be noted, are in close agreement with those obtained on the test tunnel, and percentage reductions in nitric oxide level are essentially the same for both oil and gas firing.

Since the results derived from short-term tests of Two-Stage Combustion have been favorable, this method of burning has been put into extended test operation at El Segundo. As is customary for any new development,

(*Continued on p. 404*)

Bay Area Smoke School Previewed for Press

The Bay Area Pollution Control District staff has previewed their Plume Evaluation Training Unit—"Smoke School"—to the District Board of Directors and the press.

Presently located at the Marine Corps Depot, south of Army Street in San Francisco, the unit was designed and developed by the Bay Area APCD at a cost of $12,000 to comply with one of the more important of Regulation 2, which establishes limits on visible emissions (section 3110 of the regulation). These limits call for evaluation by observers.

The unit makes black smoke and white smoke in different shades and intensities (opacity). Its purpose is to train men to understand clearly the different degrees of shade and opacity. Those to be trained include members of the District staff, city and country agencies, and other groups that will be co-operating with the District in the enforcement of Regulation 2. Specifically scheduled for intensive "Smoke School" training are officials representing, fire, health, building, zoning, and public works departments; school districts, industry, and business.

Control Officer Benjamin Linsky noted, "This unit trains people so that they know when a plume violates or conforms to Regulate 2. The regulation allows a light plume continuously and permits heavy plumes for only a few minutes each hour."

Designed by H. C. Johnson

The Bay Area APCD "Smoke School" was designed by District Engineer Herbert C. Johnson under the direction of Control Officer Linsky and John E. Yocom, Director of Technical Services. Mr. Johnson was assisted by Val Vitols, then an assistant engineer of the District, who is now with the State of California Department of Public Health. The unit was patterned after an earlier model, which was developed by the Los Angeles APCD from 1949 to 1951. However, many refinements and improvements have been made based on experience gained by the original Los Angeles model, including mounting the Bay Area APCD unit on a trailer, which enables it to be moved periodically throughout the District.

According to Joseph D. Coons, Acting Director of Surveillance and Enforcement, "The only other place where opacity training is available in the country is in Los Angeles. The ability to distinguish shades and degrees of opacity and the means for training the persons affected are inherent parts of Regulation 2. In providing this unit

(*Continued on p. 404*)

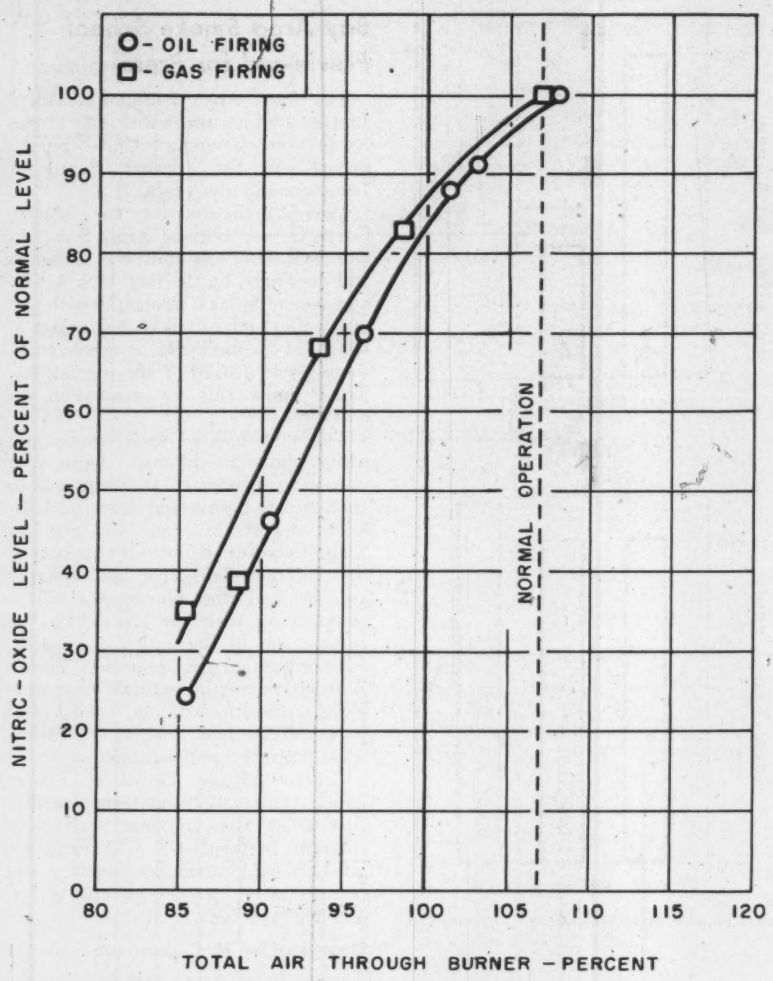

Fig. 9. Nitric oxide level vs total air through burner, Alliance Test Tunnel.

(*Continued fram p. 403*)

we are continuing to follow this operation in order to observe any long-term effects.

Summary

Two-Stage Combustion with auxiliary-air ports above the burners is an effective method for controlling the nitric oxide concentration in boiler flue gases while still maintaining acceptable boiler performance. While utilizing this method of operation, with 95% of the combustion air through the burners, the nitric oxide level was reduced nearly 30% with both oil and gas firing. A reduction of 47% occurred during full-load oil firing when the air flow through the burners was 90%.

The principal gains made in bringing nitric oxide under control are summarized graphically on Fig. 14. From this, it is apparent that Two-Stage Combustion together with minor changes to the burner (approach-cone vanes out and air registers wide open) has given a total nitric oxide reduction of 56% when firing oil at full load. As mentioned previously, similar results can be expected in gas firing. It appears that additional reductions in nitric oxide would be possible if the air flow through the burners were reduced another 5 or 10%. The limit would be reached when combustibles (carbon, CO, etc.) were detected at the furnace outlet, or when the burners became unstable. This suggests that it is important to have good operating guides for controlling the excess air in the boiler and for regulating the distribution of air between the burners and auxiliary-air ports.

The Southern California Edison Company has put the Two-Stage Combustion Method into extended test operation this year at their El Segundo Steam Station. Although the fuel-air mixing process requires careful balance between rapid mixing for best combus-

(*Continued on p. 405*)

SMOKE SCHOOL STARTS

(*Continued from p. 403*)

we are meeting one of the obligations that we undertook when the regulation was adopted."

120,000 observations by a panel of ten people have been correlated using modern computers to establish the degrees of opacity and shades of smoke in accordance with the regulation. The District reports a high degree of correlation; the exact figures are still being compiled.

Speaking on behalf of the Bay Area APCD Board of Directors, Board Chairman Andrew C. Byrd stated, "We have taken another step forward to provide the means to control air pollution in the Bay Area. The technicians and engineers on the District staff and those outside who co-operated to furnish materials and advice are to be commended for their efforts." Mr. Byrd added, "We hope that all those who could make good use of this training will take advantage of it."

Notice of Meeting Change on page 349

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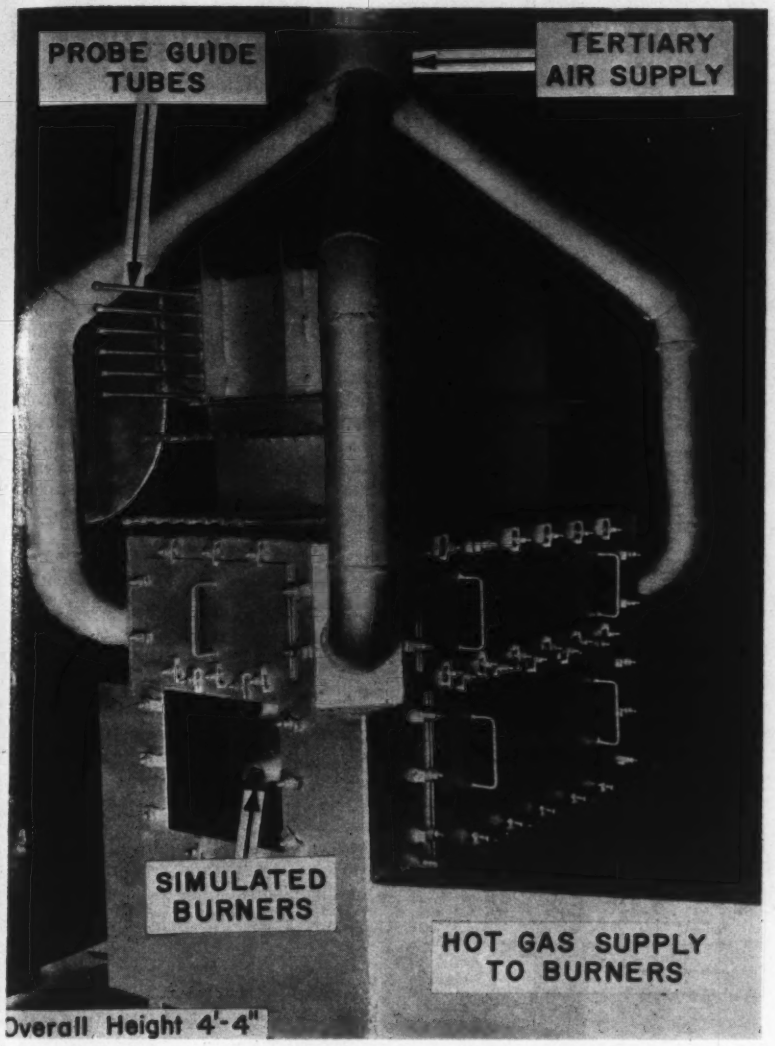
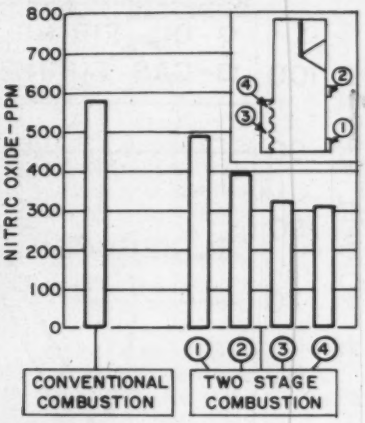


Fig. 10. Three-dimensional gas model.



NOTES:

1 Burners operated at full load, firing residual fuel oil.
2 Conventional combustion includes all registers wide open, approach-cone vanes out.
3 Two-stage combustion auxiliary air admission through:
   1 Gas recirculation ports.
   2 Rear wall ports.
   3 Second row idle burners.
   4 Top row idle burners.

Fig. 11. Nitric oxide concentration vs. locations for auxiliary-air admission, El Segundo Steam Station.

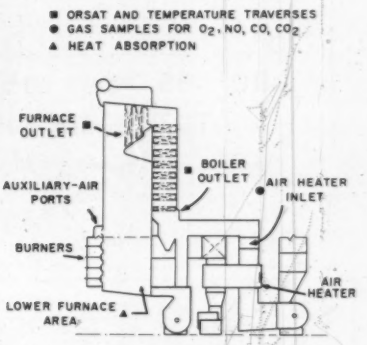


Fig. 12. Auxiliary-air port and test locations, El Segundo Steam-Station.

(*Continued from p. 404*)

tion, and delayed mixing for nitric oxide reduction, the change has not required expensive equipment nor has it involved any extensive alterations to the boiler. This method of burning has also been incorporated in the design of two new boilers for Edison's Mandalay Station and two for their Huntington Beach Station. We believe that Two-Stage Combustion is a practical operating method for the control of nitric oxide emission from large gas- or oil-fired boilers.

Acknowledgments

The authors wish to acknowledge the work of the many individuals who contributed to this investigation, chief among whom were H. C. Austin of the Southern California Edison Company, Dr. C. E. P. Jeffreys of the Truesdail Laboratories, Inc., and Dr. C. L. Ruby of the California Research Corporation.

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(*See Fig. 13 on p. 406*)

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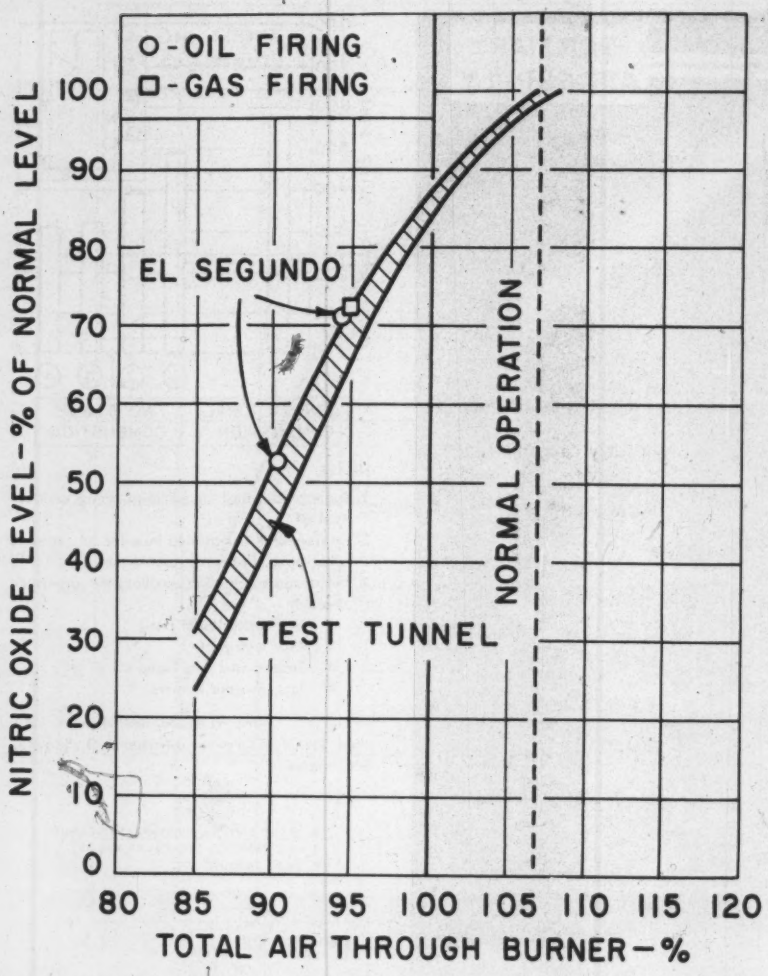

Fig. 13. Comparison of El Segundo and Alliance Test Tunnel results during two-stage combustion.

AIR POLLUTION DIVISION CREATED BY USPHS

Creation of a new Division of Air Pollution in the Public Health Service was announced by Surgeon General Leroy E. Burney.

The new Division will consolidate the research, technical assistance and training activities carried out since 1955 by the Air Pollution Engineering and Medical Programs.

"The Division will enhance and facilitate the efforts of the Public Health Service to assist States, Communities and Industry in their research and control activities in this expanding field of nationwide public health concern," Dr. Burney said. The continued emphasis on many personal, community and industrial activities which contribute to both the intensity and complexity of air pollution and the continued trend toward concentration of our population in metropolitan areas makes it clear that the nationwide threat of air pollution is becoming greater.

Control Problem Grows

The growing importance of air pollution is reflected in the acceleration of interest and activity at all levels of government and by industry, university and other private organizations concerned with furthering knowledge and abatement of a complex and growing health problem. The increase in governmental and private efforts to deal with the health and economic hazards of air pollution has been particularly notable since November, 1958, with the

(*Continued on p. 408*)

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Personalia

Patrick W. Zilliacus has been named General Sales Manager of the Western Precipitation Division of Joy Manufacturing Company according to Robert F. Stewart, Vice President of the Division. Formerly manager of agency sales for the division, Mr. Zilliacus was manager of the Standard Fan and Dust Collector Products Department of Joy from May, 1957 to November, 1959.

P. W. Zilliacus

* * *

Dr. **Philip Cooperman,** assistant professor of mathematics at the University of Pittsburgh has been appointed director of research and development for Research-Cottrell, Inc., Bound Brook, New Jersey. Dr. Cooperman formerly served in the capacity of a consultant to the firm which manufactures industrial gas cleaning equipment.

* * *

Paul E. Paules was appointed Western Regional manager for the Scientific and Process Instruments Division of Beckman, Instruments, Inc. as announced by Roy F. Brown. Mr. Paules has served in numerous capacities during his career at Beckman, and his most recent assignment was sales manager for the Western Region.

* * *

Ralph C. Graber, a career engineer officer of the Public Health Service, has been named chief of the Service's Air Pollution Engineering Program. He succeeds Frank Tetzlaff who has accepted an assignment with the International Co-operation Administration as sanitary engineering advisor to the Ministry of Health in Lima, Peru. Mr. Graber has been associated with the United States Public Health Service since 1941.

Willard P. Burdakin has joined Wheelabrator Corporation, Dust and Fume Control Division, Mishawaka, Indiana, and has been assigned to a seven-state territory including North Carolina, South Carolina, Georgia, Tennessee, Mississippi, Alabama, and Florida where he will serve as sales engineer.

(*Continued on p. 412*)

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   Company or Sustaining members: Industry affiliation or type of business (steel, petroleum, equipment, etc.).....
   .....
4. **Class of Membership (please check)**

	Dues
Individual ☐	$ 10.00
Company ☐	50.00
Sustaining ☐	250.00 Minimum

5. **Check enclosed herewith** ☐
   Send bill for dues ☐
6. **Company or sustaining member's delegated voting representative is:**
   Name.....
   Title.....
   Address.....
7. **Signed**.....
   Title.....
   Date.....

Here is an opportunity to help your Association get its membership campaign off the ground. Use this application blank for new individual, company or sustaining members. If each APCA member brings in just one new member, we'll be well over the 4000 mark.

NOMINATIONS NOW OPEN FOR APCA'S 1961 AWARDS

Nominations are in order for people to receive honors or awards given out each year by the Air Pollution Control Association. According to J. H. Smith, Chairman of the Awards Committee, these nominations constitute one of the most important activities of the year, since they promote professional interest in the accomplishments of fellow members and encouragement to all to contribute to the betterment of the objectives of the Association.

First award to be established by the Association was the Frank A. Chambers citation "for outstanding achievement in the control of air pollution" and dates back to February 12, 1954. Eligibility for this award goes beyond general excellence of work and prominence in the field into the tangible achievement in design of equipment, investigation and determination of phenomenon not previously understood, or in a scientific application of existing equipment to solve situations we never before attempted.

The second award, named in honor of Richard Beatty Mellon, was established in 1955 to honor an individual "whose contributions of a civic, administrative, technical or other nature have aided substantially the cause of air pollution control." This award can be made to members and non-members of the Association. Consisting of a certificate, this award cites the service given by an individual over a period of time to develop the acceptance of the cause of air pollution.

Honorary Membership

All members are encouraged also to recommend as candidates for honorary membership names of people of eminence in the field of air pollution control or who have rendered especially meritorious service to the Association. Those accorded this recommendation will become honorary members of the Association, having the privilege of attending meetings and other privileges of the floor, except they do not have voting privileges.

All nominations and recommendations must be accompanied by a full and detailed account of the accomplishments upon which the nomination is based. It should also be accompanied by appropriate personal and background material concerning the candidate. Five references with letters of support are required.

Chairman Smith points out that nominations should be sent to the Chairman of the Awards Committee or to any of it's members not later than January 1, 1960.

1960 PROJECT AIR LIFT GETS OFF THE GROUND WITH CELEBRATIONS

Project Air Lift is one of several events conducted annually during Cleaner Air Week, October 23 to 29. This meterological experiment is sponsored annually by APCA to emphasize the relationship of local weather conditions to atmospheric sanitation. Pilot balloons, with accompanying tags, are being released in series of 15 from over 50 cities during Cleaner Air Week.

Individual cities develop various special events in connection with the balloon experiment. Columbia, S.C., is choosing a beauty queen to reign on the day when the ballons will be launched. A group of University of Cincinnati co-eds known as the Bear Kittens will release the balloons at the U of C vs Xavier Football Game. Drum majorettes will handle the job at other intersectional and professional football games. In Texas 12 communities will conduct the experiment in liaison under the direction of state official. A similar plan is being conducted on a smaller scale in Oregon.

Helium-filled pilot ballons were first used to link metorological conditions to air pollution problems in 1953.

Each year a wide variety of patterns is developed by the course of the balloons released during Cleaner Air Week. When the balloons ascend to a high altitude without being carried horizontally, an air stagnancy is indicated.

Many air pollution problems that plagued communities in the past are being reduced through the use of meterological data in choosing industrial plant sites. Meteorological studies aid in the selecting of plant locations. Companies and communities planning industrial expansion must come to recognize that knowing what Nature is doing overhead, is as important as looking into floor factors and waste disposal problems.

Through Cleaner Air Week, the public is brought to realize that in a modern industrial community the Department of Air Purification is as necessary as a department of garbage disposal and the fire and police departments. Since purifying the air is an engineering problem, an engineer is usually in charge of the community air pollution control programs. As in other departments of public service, substantial budgets must be made available to the air purification experts, and a sensible code must be incorporated into the community' ordinances.

Cleaner Air Week provides an opportunity for air pollution control groups, civic organizations, business and industry to explain the air sanitation problem to the general public.

Activities Pooled By New Division

(*Continued from p. 406*)

National Conference on Air Pollution called by the Surgeon General held in Washington, D. C.

Chief of the new Division will be Vernon G. MacKenzie, engineer and long-time career officer in the Service, who is at present Assistant Chief, Research and Development, Division of Engineering Services. Mr. MacKenzie has worked in the field of air pollution for more than 10 years. Deputy Chief will be Dr. Richard A. Prindle, PHS career medical officer who is at present Chief, Air Pollution Medical Program. Assistant Chief of the division will be Ralph C. Graber, engineer and PHS career officer who is at present Chief, Air Pollution Engineering Program.

Creation of the new division for air pollution is a logical step to facilitate research and technical assistance efforts in a field where the interdependence of medical and engineering techniques and knowledge is widely recognized and in which research and community field studies increasingly call for the combined talents of many professional disciplines.

Staff will include physicians, sanitary engineers, physicists, chemists and other scientists and professional specialists.

Staff arms to assist the Office of the Chief in the over-all planning of activities will include, in addition to National Advisory bodies, a Program Planning and Analysis Staff, a Health Information and Education Staff and an Administrative Services staff.

The major role of research in the Division is reflected in the fact that two laboratory research branches will be established. The Laboratory of Medical and Biological Sciences will deal with medical research and some phases of agricultural research. The Laboratory of Engineering and Physical Sciences will be responsible for research into the nature, sources, and effects on the physical environment, and methods of controlling air pollution.

The Field Studies Branch will combine the epidemiologic, air-measurement, and biological-statistical activities necessary to effective research on community air pollution.

The Research and Training Grants Branch will unify both engineering and medical efforts in air pollution research and training activities sponsored by the Service in outside institutions.

The Technical Assistance Branch will provide technical services and consultation to States and local communities which request assistance in assessing and abating their actual or potential air pollution problems.

'Workshop of the World' Revamps Ideas In Fight Against Air Pollution Problems

The Pittsburgh area—with the longest background of air pollution problems in this hemisphere—has come up with a united, novel, and perhaps bold approach in continuing its historic community fight for cleaner skies. In unflagging endeavors to brighten the Golden Triangle where the Allegheny, Monongahela, and Ohio Rivers now meet in redeveloped splendor, "The Workshop of the World" has unveiled a new concept in furthering its control program.

The new concept brings into action an Air Pollution Control Advisory Committee designed to provide the best scientific talents of private industry and research to assist county officials in developing workable improvements on a new air pollution control law already acclaimed "the most exacting in the nation."

Although advisory committees in themselves are not new, "legislating" them and the duties they will perform is seen as a breakthrough in the long-talked-of theory that technical interests of the community should be officially and actively represented in municipal control and enforcement programs. This is regarded as especially important when engineering resources are vital to the operation of such programs.

In addition, the committee will be divided into subcommittees with each subcommittee stimulating research on one or more specific phases of air pollution control.

The new law, adopted as Article Thirteen of the Allegheny County Health Department's Rules and Regulations, is a consolidation of the old "smoke" ordinances of Pittsburgh City and Allegheny County. It became effective on August 1, 1960. Under the terms of the new law and with the help and support of the Advisory Committee, Allegheny County expects to achieve maximum atmospheric mundification within ten years.

New Concept, New Leader

With the new concept and the new law came a new leader. Herbert J. Dunsmore was appointed Chief of Air Pollution Control by Allegheny County Health Director Herbert R. Domke. Mr. Dunsmore is an engineer of national note. For 12 years he directed the Environmental Health Bureau, first for the Pittsburgh Health Department, and—after 1957—for the County Health Department of which the city health department became the nucleus.

This Bureau, with its Air Pollution Control Division, originally launched Pittsburgh's post-World War II attack and made smoke control the bulwark of Pittsburgh's redevelopment and renewal program. However, the job is not done, as health officials have been quick to emphasize; the problems of the future in this area, as in other metropolitan areas of the country, loom large indeed.

In accepting the new appointment, Mr. Dunsmore clarified the issue.

"Allegheny County's population is increasing. Some 300,000 more people will be added to the county's population within the next 15 years. This will mean more autos, more homes, and more refuse as well as more industry to employ this increase in the population. Each of these important community functions will contribute an increment of air pollution.

"Despite all this, however, we fully expect that new and improved control devices and greater co-operation of our residents will not only maintain the advances that have been made, but will result in even more substantial improvements in our atmosphere."

Mr. Dunsmore said his first project will be concerned with existing pollution. He—and a staff that will be enlarged—have requested a survey to establish a complete air pollution emission inventory. From this a schedule will be developed, aimed at systematic reduction of air pollution, chiefly solid particulates. The Advisory Committee, in this phase of the program, will help establish conformity schedules for every industrial, commercial, and municpal operation which is sending contaminants into the atmosphere. The Committee will submit these schedules to the Board of Health.

County industry, which already has spent more than $40,000,000 in research and installation of control devices, will be called on to exert even greater efforts in this field. Under the new law, every industry must commit itself to an extensive research and improvement program in co-operation with the sub-committees of the APC Advisory Committee.

While the massive industrial community in Allegheny County continues to suffer a number of citizen complaints regarding air pollution nuisances, County Health Director Herbert R. Domke said a nation-wide review indicates the steel industry in this county leads all other areas in the installation of air cleaning equipment. Dr. Domke added:

"The new law should further advance this position."

(*Continued on p. 410*)

Armor Develops New Technique for Monitoring Traffic

A novel technique for monitoring personnel or vehicular movement and activity by measuring the dust level in the air has been developed by Armour Research Foundation. The technique is based on measuring the concentration and size distribution of dust particles in the air utilizing a particle counter developed by ARF in 1956.

Using this technique, armies can maintain battle field surveillance of a remote area: a miniature particle counter mounted in a drone aircraft, a counter placed near a vital road junction—both of these could monitor enemy movements in the area.

Scientists working in fine particles research—once they learn the type ground and make up of the local dust—can tell how many troops are marching or how many vehicles are moving in a specific area. Even bacteriological agents can be detected by using the ARF particle counter. When all this information is assembled and combined with other known facts, it can be converted into vital intelligence.

The Armour technique evolved through a series of projects conducted for various sponsors since the particle counter was developed. These included analyses of "clean room" assembly facilities for gyroscopes and other sensitive instruments.

Dust Reduction Needed

The results of these projects indicated that certain measures should be taken by the management and employees to reduce the amount of dust suspended within the room and the introduction of dust from outside.

While evaluating and corroborating the statistical and factual data from these projects, the Foundation people were able to correlate variations in dust level and difference in dust particle size to movements and activities of the workers and machinery.

These same correlations and indices can be adapted to monitoring most any type of activity beyond the immediate area of the activity. Particle counters—now run and observed by personnel—are planned so that they require no attention and will automatically make records of dust particle counts and sizes to be collected periodically.

Particle counters can be removed from an area of activity and still monitor that activity. Movements in a room can be monitored through an air duct from a considerable distance.

(*Continued on p. 415*)

PITTSBURGH TO USE ADVISORY COMMITTEE

(*Continued from p. 409*)

The measure was more than a year in the making. The original Air Pollution Advisory Committee which drafted the measure has since been dissolved and a new group appointed to continue in the advisory roles. A list of the original members will indicate the scope of interests:

Charles H. Weaver (Committee Chairman) vice president of Westinghouse Electric Corp.; Philip A. Fleger, chairman of the Board and President of Duquesne Light Company; Prof. Theodore F. Hatch of the University of Pittsburgh's Graduate School of Public Health; Stephen M. Jenks, executive vice president of United States Steel Corp.; Dr. Campbell Moses, Jr., director of the Addison H. Gibson Laboratory at the University of Pittsburgh, Dr. M. Graham Netting, director of Carnegie Museum; Leslie J. Reese, consultant of the Pennsylvania Economy League; G. A. Shoemaker, executive vice president of Consolidation Coal Company; Morton S. Smith, vice president and regional manager of the Pennsylvania Railroad; L. P. Struble, Jr., president of Union Barge Line Corp.; Dr. Edward S. Weidlein, Sr., trustee of Mellon Institute, and Joseph Yablonski, president of District Five, United Mine Workers of America.

Broad Scope of Interests

Allegheny County Commissioners, in appointing the permanent committee, gave it even broader scope of community interests. Serving without pay, the members were appointed for terms ranging from one to three years. The new group includes several members of the original committee—Mr. Weaver, Mr. Fleger, Mr. Hatch, Mr. Jenks, Mr. Reese, Mr. Shoemaker, Mr. Struble, Dr. Weidlein, and Mr. Yablonski—and these new appointees: Mrs. Jean Nickeson, housewife; Emerson Venable, Consulting Engineer; Ross Nese, East Pittsburgh Council President; Wm. L. Feick, President, Brentwood Motor Coach Company; Dr. H. H. Schrenk, Industrial Hygiene Foundation; Attorney Charles Hodel, Allegheny County Boroughs Assoc.

As for the technical provisions of the new law, many of the emission levels of the former Pittsburgh and Allegheny County laws have been made more stringent. Although the tighter restrictions impose a greater responsibility on industrial plants, control devices which can hold emission levels to the new limits are now available.

The broad scope of the new measure implies restrictions on vapors and gaseous pollution, although the limits cannot yet be spelled out in detail. The same is true for radio-active pollution. However, a Health Department permit is required for the combustion of all radio-active waste.

Residental restrictions, on the other hand, have been eased considerably. Where the former ordinances prohibited all open fires, the new law expressly permits fires for picnics and backyard barbeques and "other recreational uses." Recognizing the problems of refuse burning, the Board of Health recommended limited control measures until adequate collection and disposal systems are established in all of the county's 129 municipalities. Coal burning and junkyard fires are rigidly controlled as in the past.

Buses, Trucks To Be Equipped

There is only one provision of the new law pertaining to vehicular exhaust. It requires all buses and trucks to be equipped with exhaust control devices within six months after one or more such devices have been placed on the market. This is a feature similar to recent legislation in California; however, Allegheny County Board of Health Chairman John A. O'Donnell noted that any restrictions now on passenger cars in Allegheny County would be "premature and unrealistic." Preliminary studies in Allegheny County indicate that highway traffic pours out about 660 tons of pollution daily.

The area's progress in air pollution control is amply demonstrated by the visibility observations of the U. S. Weather Bureau station in Pittsburgh. There has been no heavy smoke produced since 1956.

Another indication of the progress against air pollution is in the number of control devices already installed.

The steel industry here has taken the lead in the installation of electrostatic precipitators on open hearths. Twelve open hearths in Allegheny County are so equipped. Ten more are planned.

While this is just one phase of the industrial pollution problem, the progress made in other areas—electric furnaces, cupolas, coke ovens, boiler furnaces and others—will not be lost and, under prescribed research programs, will eventually be improved.

Energy consumption in any community covers the entire range of air pollution potentials. Energy consumption in Allegheny County is—on a per capita basis—50% greater than for the nation as a whole. This, fundamentally, is the cause of Allegheny County's present air pollution problems. It has been predicted that energy consumption in the nation will double in the period 1954 to

(*Continued on p. 412*)

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JET AIRCRAFT CLEARED; NOT CONTRIBUTING FACTOR TO LA SMOG

Following months of investigation, the Air Pollution Control District reported that jet aircraft are not contributing to smog in the Los Angeles Basin.

The commercial jet transports, which have been the subject of many complaints from residents of the airport area, were absolved of producing "any generalized deterioration of air quality in the vicinity of International Airport" in a report the APCD delivered to the Board of Supervisors.

Total daily pollution from all commercial jets operating at less than 3500 feet over Los Angeles County, including ground operations, was determined to be only 3.5 tons, an amount deemed "not responsible for eye irritation, plant damage, or visibility reduction in this section of the County."

Although jet traffic by 1965 is expected to increase 475%, the additional pollution will still not be of significance in the smog picture.

Jet Smoke Emissions Legal

Visible smoke emissions from the jets were labeled unsightly by the report, but were found to be within legal limits for opacity or duration.

On take-off, water injection results in relatively dense smoke, but the discharge does not exceed the three minutes permitted under the State Health and Safety Code, the APCD found. During landing and other phases of operation, smoke emitted does not exceed the lawful opacity.

The District also investigated complaints of property allegedly damaged by droplets falling from the jets. Five specific complaints were received by the APCD, and all were investigated. Chemical analysis disclosed none of the cases to be related to jet engine emissions.

In addition to the droplet complaints, another 55 complaints about jets were received by the APCD during the past year. Most of these were general objections to noise and vibration, and only incidentally to "possible" air pollution, but indicated the need for the study.

The report concluded that "the principal air pollution factor that can be deemed a possible nuisance at this time is the visible smoke plume at take-off" and recommended that the airline companies attempt to reduce this by some change in fuel, or modification of water injection practice.

Air Pollution Control Officer Smith Griswold termed the report noteworthy, not only for its comprehensiveness and

(*Continued on p. 413*)

Herbert J. Dunsmore Named APC Head; Will Enforce New County Pollution Laws

Herbert J. Dunsmore, 49, has assumed leadership of the Allegheny County Health Department's Air Pollution Control Bureau as of July 18.

Mr. Dunsmore, who has been head of the Health Department's Environmental Health Bureau for the past 12 years, will be the first permanent director of the Air Pollution Control Bureau created last year.

His annual salary of $13,236 remains the same.

At the same time, Dr. Domke announced the environmental health post vacated by Mr. Dunsmore will go to Dr. Frank B. Clack, who will be Acting Chief. Dr. Clack is head of the Food and Milk Division of the Environmental Health Bureau.

Mr. Dunsmore will be responsible for enforcement of the new Rules and Regulations on air pollution control which become effective August 1. The new law is a modern consolidation of the separate old laws of the City of Pittsburgh and the County.

H. J. Dunsmore

Dr. Domke said: "Mr. Dunsmore has been a national as well as local leader in advancing public health programs. We are particularly fortunate in having within our own staff an executive of proven ability who can begin immediately the development of a new program.

Following his appointment, Mr. Dunsmore commented:

"Our first job will be to establish a complete air pollution emission inventory. From this a schedule will be developed, aimed at systematically reducing air pollution in all its forms, in all areas of the country."

Mr. Dunsmore also will work closely with the Air Pollution Advisory Committee.

In accepting the new position, Mr. Dunsmore called on private interests from the smallest home to the largest industry to consider conditions that affect "the air we live in."

"Allegheny County's population is increasing. Some 300,000 more people in the next 15 years will mean more autos, more homes, more refuse as well as more industry to employ these people. Each of them will contribute its own increment of air pollution.

"Despite this increase in pollution, we fully expect that new and improved control devices and greater co-operation of our residents will not only maintain the historic advances that have been made, but will result in even more substantial improvements in our atmosphere."

Mr. Dunsmore becomes the fourth official figure to lead the smoke control fight since it became the bulwark of the Renaissance after World War II. Smoke Control Chief in the former Pittsburgh Health Department was Doctor Sumner B. Ely, who retired as the shift was made from city to country operation. Lee Schreibeis became air pollution chief until the division was elevated to Bureau status in the Health Department. He then became Acting Chief until recently when he left the country to join Bethlehem Steel Co., in Buffalo, N. Y. Thomas C. Wurts was Smoke Control Chief in the country outside of Pittsburgh prior to consolidation.

Mr. Dunsmore, a native of Michigan, was educated at Michigan State and the University of Michigan.

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Personalia

(*Continued from p. 407*)

Jack L. Schumann has been elected president and director of Buell Engineering Company, Inc., one of the nation's leading producers of industrial dust and air pollution control equipment, it was announced by R. F. Palyter, chairman of the board. Mr. Schumann succeeds J. A. McBride, who will continue his duties as a board member as well as consultant.

J. L. Schumann

Mr. Schumann joined the Buell organization in 1946 as a sales engineer. Ten years later, he joined Vitro Engineering Company, and subsequently served as a vice president for this organization.

* * *

Robert L. Solnick was appointed chief project engineer, Sample Handling Systems, Scientific and Process Instruments Division, Beckman Instruments, Inc., as announced by Dr. Kenneth G. Halvorsen, who is manager of engineering.

For eight years prior to joining Beckman, Mr. Solnick had been with the Fluor Corporation which is located in Los Angeles, where he served in the capacity of chief research engineer in charge of the Physical Section, Research Division.

* * *

Robert I. Peters has been named manager of Rifidon Plant of Heil Process Equipment Corporation of Cleveland, Ohio. He will be in charge of all manufacturing, estimating, and product promotion of the company's Rigidon reinforced plastic corrosion resistant process equipment including fume scrubbers, fans, tanks, tank covers, hoods, ducts, stacks, and other accessory equipment.

R. I. Peters

Mr. Peters joined the company in 1946 as an estimator, later became a sales engineer, Western Division sales manager, and more recently he was appointed to the position of assistant chief engineer.

BAAPCD MARKS MILESTONE; REGULATION NO. 2 ADOPTED

A major milestone in the control of air pollution in the Bay Area was reached on May 4, 1960, when the Bay Area Air Pollution Control District Board of Directors unanimously adopted their second regulation. Regulation No. 2, under preparation for over two years and the subject of public hearings for more than one, is a detailed measure which is designed to reduce the air pollution from a number of sources, including incineration, salvage, heat-transfer, and general combustion operations. As with Regulation No. 1, which deals with open burning, it does not place any restrictions on the daily activities of most people. The restrictions on emissions to the atmosphere became effective on January 1, 1961.

Regulation No. 2 requires that much of the industry and commerce register by September 1, 1960, if they emit air contaminants. It further requires that they reduce the amount of contaminants emitted if the amounts exceed certain limits. The regulation also states that a reasonable amount of time is to be allowed for any emitter to meet these limits.

No Permit Provisions

The basic law under which the Bay Area Air Pollution Control District operates does not provide for a permit procedure. Nor does it provide that violation of the regulation constitutes a misdemeanor. Therefore, if after a reasonable amount of time the limits are not met, injunction proceedings can be instituted which may ultimately result in a court order shutting down the emitting operation.

Specific limits for a number of contaminants have been established. Some of these have a number of exceptions to the basic limits. If an emitter can prove that an exception applies in his case he may exceed the basic limit or avail himself of alternative limits. A number of these exceptions, such as those for particulate matter, visible emissions, and sulfur oxides, are different from the regulations of other air pollution control districts in California.

Limits Differ from Others

Some of the limits also differ in other ways from those of other jurisdictions. The requirement on discrete particles from incineration and salvage operations is new. The definition of particulate matter is also different. For instance the Los Angeles County Air Pollution Control District rules and regulations specify that the quantity of particulate matter emitted be determined at 60°F while this regulation calls for determination at a temperature approximating that of the stack.

Exempt from the provisions of Regulation 2 are motor vehicles, internal-combustion engines with less than 1500 cubic inches displacement, one-and two-family dwellings, and orchard heaters.

Regulation 2

CALENDAR OF EFFECTIVE DATES

MAY 4, 1960
Regulation 2 adopted by BAAPCD Board of Directors.

JUNE 15, 1960
Printed copies of Reg. 2 available.

JULY 1, 1960
Initial Registration of existing operations begins.

SEPTEMBER 1, 1960
Deadline for initial registration.

OCTOBER 1, 1960
Deadline for submission of compliance schedule of operations which cannot meet emission limitations on or before January 1, 1961.

JANUARY 1, 1961
Deadline for compliance with Regulation 2 requirements, unless extended time schedule accepted on or before October 1, 1960.

MAY 4, 1963
Deadline for submission of compliance schedule by presently existing general operation and general combustion operations which have been in compliance with the 25% relaxation to process weight rule. (Reg. 2—Section 6113.)

MAY 4, 1965
Deadline for compliance with process weight rule of Regulation 2 by presently existing operations. (Reg. 2—section 6113.)

JANUARY 1, 1968
Deadline for full compliance by Los Angeles standard incinerators which were in existence on May 4, 1960. (Reg. 2—Section 4310.)

New Pittsburgh APC Laws

(*Continued from p. 410*)

1957. With Allegheny County carrying a proportionate share of this increase, it is evident that pollution from existing sources must be reduced and requirements on all new installations must be strengthened if the area is not to be forced into its former unenviable position as the "smoke den" of the world.

CALIFORNIA BEGINS ANTI-SMOG DRIVE; VEHICLE FUME-SUPPRESSORS REQUIRED

Smog-saturated Californians are seeking new means of alleviating their atmospheric problems. A law was passed last April by the California legislature requiring every new car registered in the state to be equipped with an anti-smog device within a year after the state's Motor Vehicle Pollution Control Board tests and approves at least two such devices. The law is designed to curb air pollution by automobile exhaust fumes.

The new legislation also provides that within three years practically all cars and trucks in the state must have the fume suppressors. The principal exception to the law—put in on behalf of smog-free rural areas in California—is that county governments may exempt used cars in those counties that rule they have no smog problem.

California's climate is partly responsible for its smog problem. Smog is principally the product of a photochemical reaction of intense sunlight, atmospheric temperature differences, weak winds, and unburned hydrocarbons in the air. Such smog stings the eyes, irritates the lungs, and damages vegetation.

The automobile long was suspected as an important contributor to air pollution. With the rapid growth of Los Angeles and the great increase in population and in the use of motor vehicles, a new type of air pollution has arisen, called photochemical smog. More recently, this type of smog has been noticed in other West Coast cities, as well as in some Eastern areas. Factory smokestacks and outdoor incineration also play a big part in creating smog.

Since a considerable amount of this air pollution is a result of gases from automobiles, an increasing number of manufacturers in the last few years have been trying to develop a device for a car's exhaust system that will burn or oxidize vapors before they reach the air.

Good Market Potential

If the procedures are successful, the market for these devices could be tremendous. For instance, California has the largest number of autos of any state with 7,500,000 registered vehicles, of which at least 6,500,000 may be required to use the smog-control apparatus.

Trade sources predict that sales of such anti-smog devices over a three-year period after they become manditory in California could amount to almost $700,000,000. They estimate the average cost of a smog-suppressor at $100.

However, these sources say that this would be only the beginning of a burgeoning new anti-smog-device industry. In time, they add, the devices might become mandatory in many other American cities that are plagued with air pollution problems. They believe sales could soar to billions of dollars a year.

Manufacturers working on anti-smog devices—automobile parts producers, chemical concerns, research companies, and a host of others—are concentrating on two main types.

One is an afterburner that uses a pilot flame. The other is a catalytic converter. To a great extent, both resemble and replace the muffler and are locked to the exhaust pipe or are placed under the car's hood.

Afterburners require only a brief warm-up time and have the advantage of longer wear. The catalyst or chemical agent in most converters must be replaced or revitalized after 12,000 to 15,000 miles of driving.

Estimates on the cost of an effective anti-smog car unit vary from $75 to $300 and more. Some Detroit retail cost estimates on either a catalyst converter or afterburner have been between $130 and $150 a unit on a new car.

The big problem in producing smog mufflers is how to cut manufacturing costs.

The present high cost of anti-smog devices results from the materials used in producing them. Many converters use catalyst made with platinum and most afterburners utilize expensive, heat-resistant steel or ceramic materials.

100 Companies Involved

About 100 companies are actively engaged in the study or development of anti-smog car devices or components.

Among these are the American Cyanamid Company. New York; American Thermocatalytic Corporation, Mineola, L. I.; Arvin Industries, Inc., Columbus, Ind.; Engelhard Industries, Newark, N. J.; Chromalloy Corporation, New York; Norris-Themador Corporation, Los Angeles; Oxy-Catalyst, Inc., Berwyn, Pa.; Thompson Ramo Wooldridge, Inc., Cleveland; Union Carbide Corporation, New York; Universal Oil Products Company, Des Plaines, Ill., and all of the major auto producers, much of whose work is co-ordinated by the Automobile Manufacturers Association.

The Studebaker-Packard Corporation is installing a smog-reducing apparatus in its 1961 Lark six-cylinder engines destined for delivery in California.

AIRCRAFT CLEARED

(*Continued from p. 411*)

results, but also because of the difficulties and hazards involved in securing the information.

Necessity of sampling jet exhaust during actual operation required APCD personnel to work near areas where the jet blast emerges at a speed of 700 miles per hour and at a temperature of 700 degrees.

Authors of the report which bears the title "Air Pollution from Commercial Jet Aircraft in Los Angeles County," are: Ralph E. George, Senior Air Pollution Engineer and Ralph M. Burlin, Senior Air Pollution Engineer. The test team was headed by Robert L. Ramlo, Air Pollution Engineer and William Oaks, Testing Assistant.

NEW AP PROGRAM STARTED BY USPHS

The Public Health Service and the Weather Bureau have begun an experimental program of forcasting air pollution potential in all areas east of the Rockies. The forecasts will be issued only when meteorological conditions favor build-up of pollutants in an area; hence, "No news will be good news," USPHS says. The forecasts will be developed at Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, and will help local pollution control and research units in setting up special studies of their problems.

Traffic Correlation Study

(*Continued from p. 388*)

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NOTICE

NEW DATES FOR 54th ANNUAL MEETING OF APCA

JUNE 11-15, 1961

These new dates have been obtained by popular demand of APCA membership through the co-operation of the Hotel Commodore management.

Water, Air Pollution Important Issues In Presidential Race

The eyes of the nation are now on the presidential race between the Republicans and Democrats, our major political parties. This time both parties paid particular attention to the urban nature of the nation and the problems created by our ever-increasing population. Both parties paid particular heed to water and air pollution.

"America can no longer take pure water and air for granted. Polluted rivers carry their dangers to everyone living along their courses; impure air does not respect boundaries. Federal action is needed in planning, co-ordinating, and helping to finance pollution control. The states and local communities cannot go it alone. Yet President Eisenhower vetoed a Democratic bill to give them more financial help in building sewage treatment plants. A Democratic President will sign such a bill. Democrats will step up research on pollution control, giving special attention to: *(1)* the rapidly growing problem of air pollution from industrial plants, automobile exhausts, and other sources; and *(2)* disposal of chemical and radioactive wastes, some of which are now being dumped off our coasts without adequate knowledge of the potential consequences"—Democratic.

"We pledge: Strengthened federal enforcement powers in combatting water pollution and additional resources for research and demonstration projects; Federal grants for the construction of waste disposal plants should be made only when they make an identifiable contribution to clearing up polluted streams; Federal authority to identify, after appropriate hearings, air pollution problems and to recommend proposed solutions; Additional resources for research and training in the field of radiological medicine"—Republican.

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W. H. WHEELER DIES; PIONEERED ODOR CONTROL

William H. Wheeler, President of Airkem, Inc., died July 23 at the age of 73. Mr. Wheeler founded the odor control pioneering firm in 1941 and led it to world-wide prominence. From his headquarters in New York City, Mr. Wheeler directed the activities of the parent company which operates through distributors in 135 countries of the free world.

W. H. Wheeler

At the age of 56, William H. Wheeler resigned his position as air conditioning sales engineer to make a commercial success out of an intriguing new formula. The product, a combination of 125 compounds, was developed to counteract odors generally found in indoor areas. In addition to odor control, the product, because of its chlorophyl content, added an air-freshened effect.

Acceptance of the new product came almost overnight from both industrial and home users. Through retail distribution as "air-wick," the product became a familiar sight in its unique wick bottle. Today, through many such well-known companies as Lever Brothers and Horlick's Ltd., the Airkem product is sold for use in homes around the free world.

Coincidental with the growth of consumer products, Airkem under Mr. Wheeler's direction, rapidly expanded its distribution of industrial and institutional products. The basic concept of odor counteraction led to the development of specific products to control the many types of odor and sanitation problems facing business and industry. Airkem research, which was of vital interest to Mr. Wheeler, found application for the Airkem products in industrial process odor control, smoke odor removal, removal of product odors, and a complete group of sanitary maintenance products incorporating Airkem odor control.

Mr. Wheeler was a member of the American Society of Heating and Ventilating Engineers. He received a degree in Mechanical Engineering from Columbia University in 1911 .

Mr. Wheeler had recently launched a Plan for Presidents, which through his efforts reached presidents of many corporations in the United States who were urged to follow his leadership in having their employees support Project Hope.

EMISSION STANDARDS

(Continued from page 396)

adopted by the California State Department of Public Health included hydrocarbon monoxide. The standards represent a first attempt to set vehicular emission standards as a basis for control legislation. Judgments and decisions were of necessity made on the basis of present knowledge of the smog problem. As new data become available, the standards will be revised. The process of considering the standards has in itself been useful in defining questions which must be answered in order to make sound decisions in the field of vehicle exhaust control. The setting of the first numerical standards should not be allowed to detract from continued research into the mechanism of smog formation and the relative contribution of the motor vehicle.

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AEROSOL SPECTROMETER

(Continued from p. 389)

Peter K. Müller, State of Calif., Department of Public Health, Berkeley, Calif., for putting their first attention to the existence of the by-pass phenomena in the instrument and the basic procedure leading to the flowmetering methods described in this report.

The authors wish to express their appreciation to the manufacturer of the Aerosol Spectrometer for technical assistance and the permanent loan of an instrument.

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(Continued on page 416)

FINAL PLANS ARE SET FOR CAW

FINAL PLANS—The Cleaner Air Week Program for 1960 was the major topic of discussion at a join meeting of two committees of the Air Pollution Control Association. The session took place at the new Coal Building in Washington June 30. Pictured from left are: Harry C. Ballman, director of the Air Pollution Control Department, National Coal Association; Kendall Beaton, assistant to manager, Public Relations, Shell Oil Company; Charles N. Howison, chairman, Cleaner Air Week Committee, Air Pollution Control Association, and director of Air Pollution Control League of Greater Cincinnati; Joseph H. McGinty, staff assistant, Administration, Public Relations Department, U. S. Steel Corporation; and George T. Minasian, chairman, Public Relations Committee, Air Pollution Control Association.

The week of October 23 to 29 will be the nation-wide Cleaner Air Week, sponsored by the Air Pollution Control Association.

Each day of that week has a special emphasis and objective and it is hoped that through the local committees, organizations, and groups will work together to achieve these goals. Throughout Cleaner Air Week, special days have been designated to emphasize specific objectives of the campaign. It is hoped that those organizations and groups who are specifically interested will work with the local committee.

Sunday—Community Sunday, on this opening day stress the importance of the community-wide approach to air pollution control.

Monday—Housekeeping Day, collect rubbish, dirt, and waste materials for pick-up. Do not burn. Junior Chamber of Commerce may undertake promotion of this effort.

Tuesday—Home Heating Day, clean furnace, flues. Check maintenance needs. Clean chimney. Co-ordinate with furnace cleaning firm.

Wednesday—Automobile Day, does your exhaust pipe smoke? Co-ordinate inspection drive.

Thursday—Industry Day, arrange industry tours for air pollution control progress of your community plants.

Friday—Air Pollution Control Official Day, publicize the work of your air pollution control officials; pay tribute to their important public service.

Saturday—Examination Day, grade your community-wide efforts in all phases of air pollution control.

ARF DEVELOPMENT

(*Continued from p. 409*)

Dust monitoring can be used in detection applications—either military or civilian—where infrared or ultra violet systems cannot, or where the use of such systems with their giveaway electronic characteristics would compromise the location or presence of a monitoring system.

Help Boost APCA Membership

(*See page 407*)

SECTION HI-LITES

(*Continued from p. 392*)

Most are direct-fired. Steam and smoke emissions are slightly above the opacity rating allowed by Regulation 2. Opacity may be eliminated by burning the smoke in an afterburner, which may, in the case of batch roasters, double the fuel bill. Capital cost of control equipment will approximate one-sixth to one-third of the original plant cost. "The roast coffee odor, as well as the romance, will disappear with the smoke."

Herb Johnson, principal engineer, Bay Area Air Pollution Control District, discussed incinerators and heat transfer operations. He pointed out that difficulties in the heat transfer field would be faced chiefly by oil-fired burners with short stacks where there are hills downwind. There would be no ash problem, but a ground-level sulfur dioxide problem could develop. With regard to refuse disposal, Mr. Johnson stated that revision of archaic incinerators would not be worthwhile.

Hansing Final Speaker

The final speaker was James R. Hansing, senior technologist of Shell Oil Company. He spoke chiefly of the severe restrictions placed on fuel burning by the opacity requirement of the regulation. Opacity equivalents of black smoke were originally developed for solid fuels. He said fuel oil was usually considered a clean fuel, but use of the opacity equivalent was two or three times more restrictive than would be indicated by normal use of the Ringelmann chart. He foresaw no problem in complying with the ground-level sulfur dioxide concentrations stated in the regulation. On the other hand, the limits on particulate matter from regenerating fluid catalytic cracking units was extremely restrictive, with allowable losses of only one part in ten thousand. He affirmed the desire of the petroleum industry to co-operate fully with the Air Pollution Control District. He recalled that although the oil industry is fiercely competitive, its members co-operate fully in the development of air and water pollution controls.

Another dinner meeting of the West Coast Section of APCA was held at Montclair in Southern California on July 28. Eighty-four members and guests attended.

Dr. C. Ray Thompason of the University of California, Riverside, described the Agricultural Air Research Program (AARP) recently initiated on the Riverside campus. The two million dollar program is jointly supported by

(*Continued on p. 416*)

Rutgers University Begins 2 AP Courses

Rutgers The State University is offering two courses in air pollution for the academic year 1960–61.

The first term is Principles of Air Pollution Control, three credits, which is designed to familiarize the student with the fundamental factors responsible for atmospheric contamination, the effects of pollution on man and his environment, the basic principles of measurement, methods of control and gas cleaning, and some knowledge of the legal aspects involved.

This course is under the direction of the Department of Sanitation in co-operation with the Bureau of Biological Research, Department of Meteorology, Department of Plant Pathology, the Nuclear Science Center of Rutgers, and the New Jersey State Department of Health, Air Sanitation Program.

Basic Techniques

A course in Air Sampling and Analysis is offered second term and this is a course providing training in the basic techniques of sampling and analysis of community atmospheres, source emissions, and vegetation; application of of air pollution; field study of an air pollution problem; planning and carrying out of survey; evaluation and interpretation of results.

This course is under the direction of the The Department of Sanitation in co-operation with the Department of Meteorology, Department of Plant Pathology, and the Nuclear Science Center.

It is open to qualified graduate and undergraduate students of Rutgers and to industrial, governmental, and other professional personnel interested or engaged in air pollution control. The background of those taking this course must include basic courses in college chemistry and physics, or their equivalent.

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AIChE, MIChE MEMBERS ENJOY TALK DURING UNIT OPERATION LUNCHEON

INTERNATIONAL—Enjoying a Unit Operation luncheon at the Hotel Del Prado in Mexico City are members of the American Institute of Chemical Engineers and the Mexican Institute of Chemical Engineers who are discussing air pollution problems. Pictured from left are: Robert Cabellero, Martin Smith, J. P. Shambaugh, Paul Cater, W. L. Faith, Humberto Bravo, Arnold Arch, and Adalberto Tirado.

SECTION HI-LITES

(*Continued from p. 415*)

San Bernardino County, private agricultural and industrial interests, and the University of California. Goal of the program is determination of the effects of atmospheric oxidants and fluorides on citrus fruit. Groups of producing citrus trees will be encompassed in large plastic enclosures. One group will be subjected to the ambient polluted air, another to purified air, one to oxidant-free polluted air, and one to fluoride-free polluted air. Methods for removing oxidant from ambient air without affecting the fluorides, and vice versa, are being devised.

The second speaker was Dr. Moyer D. Thomas, noted air pollution expert, also engaged in the AARP at Riverside. He spoke on "Instrumentation in Air Pollution Research."

AEROSOL SPECTROMETER

(*Continued from page 414*)

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CLASSES FOR AP OFFICIALS OFFERED BY TAFT CENTER

Control of air pollution emissions is the subject of two consecutive one-week courses designed for air pollution control officials by the Training Program, Robert A. Taft Sanitary Engineering Center, PHS research and engineering laboratory in Cincinnati. For the convenience of those desiring to cover both aspects of the problem, "Control of Particulate Emissions," November 7 to 11, is followed by "Control of Gaseous Emissions," November 14 to 16. In both courses, applicability and performance of various types of equipment and procedures are considered.

Covered in the first course are theories of particulate precipitation, measurement of collector efficiency, gravity settling chambers, centrifugal and other inertial collectors, fabric and wet collectors, electrostatic precipitators, and costs and application of collectors. The second course covers such topics as meteorological control, collector efficiency, absorption and adsorption equipment, incineration, catalytic combustion, and source control. Both courses consider problems of sanitary disposal of collected material and legal and administrative aspects.

Applications or requests for information should be addressed to the Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio, or to a PHS Regional Office Director.

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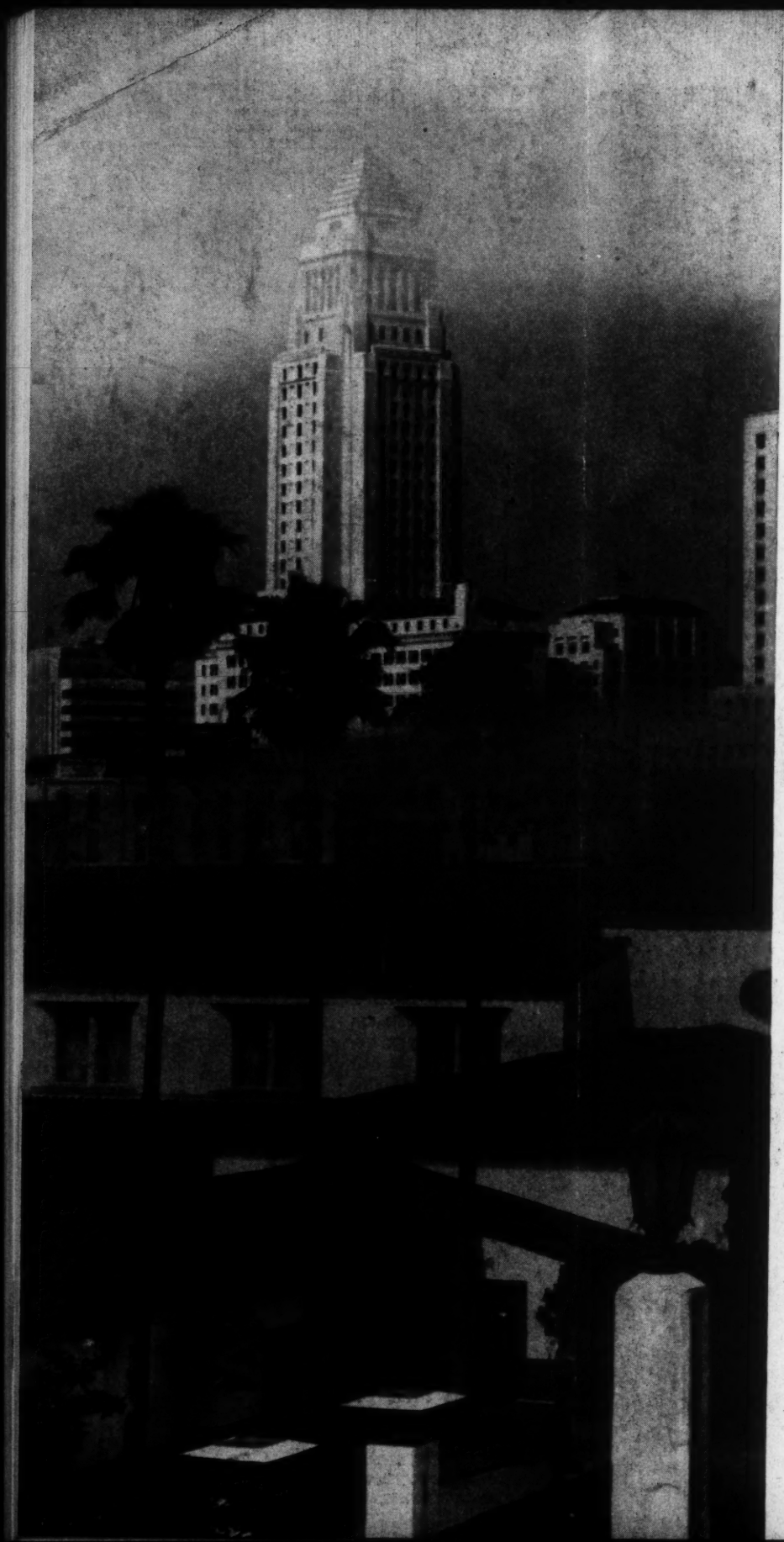

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